

R E P O R T R E S U M E S

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FOUR STUDIES INVOLVING THE USE OF PROGRAMED MATERIALS IN
ENGINEERING EDUCATION.

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FOUR EXPERIMENTS WERE CONDUCTED TO EVALUATE PROGRAMED
INSTRUCTIONAL MATERIALS DESIGNED FOR TEACHING CIRCUIT THEORY
AND FORTRAN AT THE COLLEGE LEVEL. IN THE FIRST EXPERIMENT,
APPLICATIONS OF PRINCIPLES CONCERNED WITH PROACTIVE AND
RETROACTIVE INHIBITION (NEGATIVE TRANSFER OF LEARNING) WERE
STUDIED. THE REMAINING THREE EXPERIMENTS WERE DESIGNED TO
STUDY EFFECTS OF (1) IDEATIONAL SCAFFOLDING (SUMMARIZATION)
PRECEDING PROGRAMED SEGMENTS OF A BRANCHING TEXT, (2)
LEARNER-DETERMINED ALTERNATIVES IN A BRANCHING PROGRAMED
TEXT, AND (3) EFFICACY OF WRITTEN AND READING RESPONSES TO A
LINEAR PROGRAMED TEXT. MATERIALS TESTED IN THE FIRST
EXPERIMENT GENERATED RETROACTIVE AND PROACTIVE INTERFERENCE.
SUMMARIZATION PRIOR TO A PROGRAMED INSTRUCTION SEGMENT HAD NO
BENEFICIAL EFFECT. THE THIRD STUDY INDICATED THE NECESSITY OF
OBTAINING HIGHLY DETAILED FEEDBACK FROM LARGE GROUPS FOR
DEVELOPING BRANCHING TEXTS. WRITING OF RESPONSES DID NOT
INCREASE IMMEDIATE OR DELAYED RECALL OF PROGRAMED FORTRAN.
IMPLICATIONS OF THE EXPERIMENTAL FINDINGS WERE DISCUSSED FOR
SUBSEQUENT RESEARCH AND DEVELOPMENT OF PROGRAMED INSTRUCTION
MATERIALS. (WN)

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JOHNS HOPKINS UNIVERSITY

DEPARTMENT OF
ELECTRICAL ENGINEERING

Four Experiments in Engineering Education

by

Doris R. Entwisle

Title VII Project Number 1012

National Defense Education Act of 1958

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Four Studies Involving the Use of Programmed Materials
in Engineering Education

by

Doris R. Entwisle

Title VII Project Number

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Introduction

Four studies involving the use of programmed materials have been carried out during the academic year 1962-63 with students at Johns Hopkins University enrolled in the course "Introductory Systems and Design". The studies deal with diverse topics, and a description of each, together with results, will be presented separately.

Before discussing the individual studies, it should be pointed out the course Introductory Systems and Design, formerly known as Circuit Theory, represents an attempt to build a master course suitable for all beginning engineering students. The course material is organized so that its full generality applicable to all fields of engineering will be apparent, and both digital and analog computers are emphasized as models of "systems".

Experiment I. Retroactive Inhibition in Learning^o of Circuit Solutions.

Special Note

As originally planned, this experiment was to include three groups, two experimental and one control. The second experimental group was to be included so that ideational scaffolding could be tested as a means of counteracting retroactive inhibition. A prior experiment, supported by another agency (Contract-AF(628)-263 with the Operational Applications Laboratory, Electronic Systems Division, Air Force Systems Command) and reviewed briefly below, served as a "pilot study" for Experiment I. This pilot study suggested very strongly that with the actual number of students available to serve as subjects it would be impossible to study three groups simultaneously without reducing the number of students per group to such dangerously low levels that the risk of Type II errors would be sizable. It seemed preferable, therefore, to modify the experiment somewhat in view of the pilot study results, rather than assume a considerable risk that the entire experiment would be vitiated. The complexity of the experiment was increased along another dimension: studying proactive as well as retroactive inhibition. Actually, the results of the revised experiment turned out to be very significant, and when added to the results of the pilot study leave little doubt of either the importance or the substantial magnitude of interference effects in the learning of circuit theory as conventionally presented. The results of Experiment II, furthermore, which bear directly on ideational scaffolding, and are directed toward the same problem in a slightly different setting, were negative. It therefore appears in retrospect that the judgment to revise Experiment I was a very fortunate one. Because of the results of Experiment I the lecture schedule in the remainder of the course was revised. The benefit from this change in schedule was impossible to assess objectively, but

questionnaire data from students and the instructors' evaluation of student performance subsequent to the change suggest that it was indeed beneficial.

Purpose

The purpose of this experiment was to try to demonstrate both retroactive and proactive inhibition when the dual node-pair and mesh methods for solving circuit problems were consecutively presented.

Background

Electrical circuits are solved by setting up sets of equations, where the number of unknowns equals the number of equations. These equations can be written so the dependent variables are either voltages or currents. Teachers usually try to emphasize both methods about equally, because for some problems the loop method is easier to apply, while for other problems the node-pair method is more suitable. Somewhat different sets of rules apply, depending upon which method is used. This duality--sets of similar rules and principles--is characteristic of the entire body of circuit theory, and affects time-varying as well as stationary circuits.

Apparently teachers of circuit theory have been unaware of the theory involved in transfer of training, and especially of the kinds of learning situations that may produce negative transfer. The way in which circuit theory is conventionally taught appeared to exemplify a situation that might generate considerable amounts of negative transfer: the principles to be learned are very similar and yet not identical.

Although there appear to be no previous experiments on precisely the topic of this experiment, there are many experiments on transfer reported for other kinds of learning situations. In general (Woodworth & Schlosberg, 1954; Deese, 1956), there is agreement that different stimuli presented with the same response yield maximum positive transfer, and that similar stimuli to be

connected to different responses yield maximum negative transfer. This generalization has some exceptions, however, and as Stephens (1960) says: "When dealing with a given stimulus the most devastating thing may not be a shift to a very different response, but a shift to a response that is only slightly different. It is when two responses have so much similarity that they can be confused that we get our greatest negative transfer." (The experimental studies upon which Stephens bases this conclusion will not be re-cited here.)

Prediction of negative transfer based on theoretical considerations are hazardous, however, particularly when meaningful materials are involved. Hall (1955) did not find inhibition when very similar meaningful material was interpolated between prior material and a later test. Therefore, the present experiment was undertaken to see whether negative transfer did occur when circuit theory was taught in the standard manner.

A preliminary experiment (pilot study)

One serious obstacle in investigating learning materials that form part of a college course and in using regularly enrolled students is the "time factor". Experiments must be limited to one class period in which there is complete control over activities of the learners, especially the stimulus materials available. If experiments are lengthened to cover more time than the time directly under E's control, many confounding variables can come into play, and this prevents the drawing of straightforward inferences as a result of an experiment. This fact is frequently overlooked by persons trying to study school learning, with the consequence that very little precise knowledge exists about school learning.

A pilot study, which happened to turn into a well-designed experiment, was undertaken to see if it was possible to demonstrate negative transfer in the learning of circuit theory when the entire experiment was compressed into one 50-minute class period. The experimental materials are presented in Appendix A. The design was as shown below, with the experimental and the control groups each

formed randomly with five ability-level strata.

	Treatment 1 (15 minutes)	Treatment 2 (15 minutes)	Test (20 minutes)
Experimental group	Study voltage principles	Study similar current principles	Test on voltage principles
Control group	Study voltage principles	Study irrelevant material	Test on voltage principles

The analysis of variance of error scores on the test (shown in Table 1) revealed: superior performance (.02 level) by the control group, and no interaction between ability-level and experimental treatments.

Table 1

Source of variation	Degrees of freedom	Sum of Squares	Mean Square	F Ratio	P(F)
Experimental vs. Control	1	20	20	4.69	<.02
Ability Strata	3	11	3.67	---	
EC x AS	3	15	5.00	---	
Residual	66*	281	4.26		

*6 d.f. deducted for missing values

Besides indicating the probable existence of negative transfer in the learning of circuit theory as conventionally presented, this experiment indicated that 1) at most two treatments and one test could be included within one class period; 2) the use of ability-level as a control variable did not permit the extraction of additional variance; 3) groups of about the size used would probably be needed to demonstrate negative transfer in the experiment to come, and reduction of group size might be accompanied by a serious danger of making a Type II error (failing to observe a difference when a "true" difference exists). These considerations led to the revision of Experiment I, changing it from the

original plan, as already discussed above in the Special Note.

After the pilot experiment, three lectures intervened before Experiment I: The topic of branches in a circuit and the corresponding 2b equations was presented. The next lecture would have ordinarily introduced the node-pair and loop methods.

Method

The principles of node-pair and loop solutions in stationary circuits provided the materials used in the experiment. It was hypothesized that an experimental group who read material on node-pair solutions and then immediately read the corresponding principles relating to loop solutions would retain less of the node pair material than a control group. The control group would read identical material on node-pair solutions, but afterward read material on matrix theory (irrelevant material). This part of the experiment exactly replicates the pilot study. But in the experiment proactive inhibition is also investigated.

The post-test used in Experiment I included two sub-sets of 6 items each, one set on node-pair and the other set on loop solutions. The two sub-sets were exactly alike in sentence construction and tested dual concepts. For example, two parallel fill-in questions were:

1. The fundamental principle used in writing loop equations

is _____. ANSWER: $\sum v_k = 0$

2. The fundamental principle used in writing node equations

is _____. ANSWER: $\sum i_k = 0$

The two sub-sets of questions were thus exactly equivalent. Also, in the same sense, the readings on node-pair and loop solutions were parallel. For this reason, performance on the two sub-sets of 6 items should be the same, unless other factors are at work. This matter is very important to the interpretation of the experiment, as will be clearer later. The two sub-sets of six questions

were inbedded within a larger set of questions so that the correspondence between them would not be obvious. Each member of a pair was on a separate page, and unrelated questions intervened. Also students were instructed not to return to earlier questions once they had been answered. Students were ranked in order of mathematical aptitude and successive pairs within this ranking were randomly assigned to the control and experimental groups.

The design for the experiment was:

Experimental Group	Learn node-pair principles	Learn dual loop principles	Parallel tests on both node and loop principles
Control Group	Learn node-pair principles	Learn irrelevant material on matrices	Parallel tests on both node and loop principles

Fifteen minutes was spent studying each unit of material, and the test consumed the remainder of a class period. The experimental reading materials and the post-test are presented in Appendix B.

Results

Errors made by the students on the post-test were subjected to an analysis of variance. This is shown in Table 2.

The actual analysis of the experiment, however, hinges on the 2 x 2 table shown below (Table 3) where entries are the errors made by both groups on the two equivalent sub-tests.

Table 2

Source of variation	Degrees of freedom	Sum of Squares	Mean Square	F Ratio	P(F)
<u>Between individuals</u>		124			
Experimental vs. Control	1	0			
Error between (E_b)	52	124	2.38		
<u>Within individuals</u>		78			
Node vs. Loop	1	24			
NL x EC	1	11	11	13.30	<.001
Error within (E_w)	52	43	0.827		

Table 3

Errors on Sub-tests

	Node Subtest	Loop Subtest	Total
Experimental group (studied each set of material 15")	93	101	194
Control group (studied node material <u>only</u> for 15")	76	119	195

The control group made fewer errors on node questions than the experimental group (76 vs. 93 respectively), and this difference is statistically significant beyond the 0.05 level. Thus studying loop principles after studying node-pair principles interferes with retention of node-pair principles (retroactive inhibition), and the result of the pilot study is replicated. However, the analysis shows in addition that learning node principles interfered with subsequent learning of loop principles. The experimental group made more errors on loop principles than the control group made on node principles (101 vs. 76). Since the node and loop materials that were studied and the node and loop subtests were exactly parallel, studying one set of principles for 15 minutes should

lead to the same outcome as studying the other set for 15 minutes. But the fact that the experimental group has just previously studied node principles prevents them from learning as much about loop principles as they should be expected to learn. The control group, with prior time spent in irrelevant activities, made significantly fewer errors after spending the same amount of time studying an equivalent body of material and completing an equivalent test.

In testing the differences between these error scores, a t-test is used where the standard error of the difference is a weighted combination of the error between, E_b , and the error within, E_w , of Table 2. To test for retroactive inhibition

$$t_{52} = \frac{(93-76)/27}{\sqrt{2[0.827+2.38]/54}} = 1.83$$

This test is one-tailed and $P(t_{52})$ is considerably smaller than 0.05.

Similarly to test for proactive inhibition

$$t_{52} = \frac{(101-76)27}{\sqrt{2[0.827+2.38]/54}} = 2.70$$

and this hypothesis is substantiated at an even higher level of confidence.

It should be noted that comparable results for retroactive inhibition from both the experiment and the pilot study, conducted as independently as possible, increase the credibility of the result. In particular, subjects were randomly assigned independently in the pilot study and experiment.

Discussion

It appears that proactive interference was about equal to retroactive interference in this experiment. Thus the interference is double-barreled: learning node material first interferes with later assimilation of loop material, and later learning of loop material retroactively interferes with the previously learned node material. The overall decrement is therefore about twice as large as the decrement for each topic considered separately.

One result in the 2x2 table deserves emphasis. It will be seen that there is no difference in total errors (194 vs. 195) made by the experimental and control groups. Since these errors stem from test items relating both to node and loop principles and the control group did not see the material on loops, it appears that 15 minutes spent reading node material leads to about the same increment in learning as 30 minutes spent reading the two interfering sets of material. Thus whatever is learned from reading neutral material represents an additional increment for the control group.

These results should be considered in light of several factors. First, the same general results from two independent experiments leaves little doubt that negative transfer can occur in the learning of circuit theory. Second, these experiments were done under the extremely constrained circumstances that go hand-in-hand with using actual course material and regularly enrolled students. The time limitations are very serious, for it is likely that a certain minimal amount of learning must occur before interference would set in. For instance, if only one node principle and one loop principle were presented, both might be perfectly reproduced by all students even if the dual principles were harder to learn than two node principles. Yet with only 15 minutes available for study, the interference is observed. Third, by the time of the experiment students had already had considerable exposure to circuit theory. If, as has been shown, the material generates interference, the basal level of interference in all students might be rather high. In this event it would be correspondingly difficult to "add" to the basal interference level enough further interference within the period of a few minutes so that a difference between control and experimental groups could be produced. Also, of course, some students had considerable knowledge of circuit theory before the course started, and they contribute "noise" to an experiment of this kind.

Consideration of these factors suggests that the interference must be pronounced to appear under such generally adverse conditions. That retroactive inhibition was observed for both node and loop materials and that both retroactive and proactive inhibition were observed confirms one's intuition that these two sets of principles are equally suspect in causing negative transfer. Since the duality inherent in circuit theory is not confined to the particular topics used in these experiments but rather is characteristic of the entire body of theory, we conclude with some confidence that interference of the type demonstrated may be a continual source of difficulty to beginning students.

The results of this experiment have far-reaching implications for the teaching of circuit theory, a topic taught in almost all four-year colleges in the country. It appears that currently available texts, and most teachers, are presenting this material in such a way as to increase greatly the difficulty of the material. In both the pilot study and the experiment, the teaching of dual sets of principles, one after the other, caused measurable interference in learning. In the experiment it is clear, furthermore, that interference works proactively as well as retroactively. These results indicate that the simultaneous presentation of dual concepts should probably be avoided with beginning students. Although the experiment was not capable of indicating a way of presenting this material to reduce interference, some modifications were made in the organization of ensuing lectures in the hope that interference would be reduced. The theory of transfer suggests that overlearning may counteract negative transfer. Therefore, after the topic of node-pair solutions had been introduced by the experiment, this topic was covered in its entirety before the dual topic, mesh solutions, was introduced. (Previously attention was divided between the topics, so that one aspect of node-pair methods was immediately followed by the parallel aspect of mesh methods.) This sequence should be

beneficial for two reasons. (1) The learning of advanced topics is accompanied by some review and drill on earlier topics, thus forcing the overlearning of the earlier topics. (2) Covering an entire topic allows its overall conceptual structure to be made apparent and perhaps to crystallize in the minds of students. From a theoretical standpoint, increasing the meaningfulness or structure inherent in material to be learned reduces the likelihood of negative transfer.

Although there is no objective evidence on the efficacy of this modification in the lecture schedule, there are some grounds for thinking the change was beneficial.

At the end of the semester, students filled in an opinionnaire anonymously, and one question was:

"Because of experimental findings node solutions were treated at great length and in great depth last semester before mesh solutions were introduced. Did you think this helped you? Yes _____ No _____ Why? _____"

"If given a choice, which method of solution would you prefer to use? _____"

About 95 per cent of the students thought they were helped by this method of presentation, and the reason most often given was that it tended to reduce confusion. Of course their feeling that confusion was reduced is somewhat illogical since they had not had an opportunity to sample confusion when both methods are taught simultaneously. Several students commented, however, that they were confused when both topics were treated together in the experiments, and one student said he tried to study both at the outset using one of the recommended textbooks and gave up because he became confused. As far as preferred method of solution is concerned, about half prefer the node-pair method, one-quarter feel equally at home with either method, and one-quarter prefer the loop

method. Unfortunately a similar question was not asked in previous years when mesh solutions were introduced first and both methods then taught almost simultaneously. It is our impression, nevertheless, that students in previous years have greatly preferred the mesh method, if a choice were available.

Most important of all, the experiment also has some profound implications in the area of programmed learning. Several other topics in the course in Introductory Systems and Design had already been worked into programmed booklets (digital computer programming, signal flow-graphs, signal generators, etc.), but because of our suspicion that negative transfer might be generated when circuit theory was presented in the conventional manner, it was decided to delay attempts to program materials in this area until the negative-transfer hypothesis was investigated. The experiments indicate very clearly that the organization of most modern texts on circuit theory probably produces serious interference, and it is very likely that these texts would have served as a point of departure for programming efforts in this area. Plans for programming have been drastically revised.

These experiments have more general implications as far as programmed learning is concerned. The empirical testing of programmed materials on circuit theory (or on any other topic) would be very unlikely to reveal any problem of negative transfer or to provide a solution for it. Ordinarily a programmer selects a topic to be taught and then proceeds to fragment it into small units that serve as steps in either a branching or linear sequence. But the sequence of steps selected at first usually mirrors the sequence of topics in a conventional text or in a lecture series. The programmer customarily assumes, perhaps not even explicitly, that the broad organizational sequence of topics is a good one. This assumption is never tested when feedback from students is obtained in order to refine the program. Thus the probable refinements intro-

program would center around increasing redundancy in the program. There would be no clue from students' responses that an overall and sweeping organizational change in the material might greatly aid learning, and once a programmer has developed a program to the point of an empirical test he is naturally reluctant to make sweeping changes because these necessitate beginning the empirical testing anew.

The experiment suggests that considerations drawn from psychological theory may suggest very fruitful hypotheses for experimentation in higher education.

There is presently a large and unfortunate gap between theory developed in the psychological laboratory and classroom teaching, especially at the college level. This experiment was an attempt, that turned out very successfully, to draw upon that theory to improve the teaching of some materials in a basic engineering course.

Experiment II. Ideational Scaffolding Preceding Programmed Segments from a Branching Text on Flowgraphs.

Purpose. The purpose of this experiment is to test the efficacy of a preceding summary in conjunction with programmed materials (branching texts on signal flowgraphs) and to see if efficacy is related to ability level of students.

Background. With programmed materials, whether of the linear or branching type, the aim is for students to master successive small units. This fragmentation of the material permits reinforcement to be given quickly and often, and so presumably aids learning. In developing programmed materials little attention has been paid, so far, to devising programs that might attempt to capitalize on principles from gestalt and other cognitive theories simultaneously with principles from reinforcement theory.

Students frequently complain that after finishing a programmed text they have difficulty in reconstructing mentally the relations among the main concepts that have been covered. With material presented in very small steps they have trouble "seeing the forest for the trees". Also reviewing is difficult for the student because programmed materials do not lend themselves to facile review coverage.

It appeared that one device to implement cognitive theory and also to meet students' objections would be a preceding summary: an ideational scaffold to point out interrelations and structure of the material to be presented. This summary would serve to structure subsequent material in the programmed segments.

Programmed materials which de-emphasize structure may not be optional for students of high ability, because there are suggestions in the literature that these students may learn more readily if material is presented in terms of abstract and general concepts. Osler and her associates (1961) found that

children of high intelligence discover concepts by the testing of successive hypotheses, whereas children of average intelligence apparently attain concepts by a process more like trial and error. Since Osler's observation was independent of age over the range studied, it seems likely that similar differences in concept formation may characterize college-age individuals. In fact, since college students are generally at least as bright, in terms of IQ test scores, as Osler's "highly intelligent" children, they may characteristically learn by hypothesis testing. (In passing, it should be mentioned that if this is the case, then one might suspect that branching programs would be more suited to college students than linear programs, although there is little research to suggest that one type of program is superior to another.) Osler found that extraneous stimulus dimensions abolished the difference in performance between bright and average children. This suggests that some methods of presentation could actually handicap bright students. If bright students find total concepts easier to assimilate than the same concepts presented piecemeal, present procedures for programming learning may fail to capitalize upon this.

Experiments by Ausubel & Fitzgerald (1960) show that for conventional material prior scaffolding aids both acquisition and retention, but especially retention. From a common-sense viewpoint, one would suspect that prior scaffolding will aid in learning programmed material, since little structure may be apparent in the material when it appears in small units.

Because of the results of Experiment I and the nature of the subject-matter in signal flowgraphs, the summary actually tested contained information that might serve to reduce negative transfer from circuit theory to concepts in flowgraph theory. In particular (see Appendix C), the important definitions of nodes, branches, loops are different in circuit diagrams and in flowgraphs and the rules for reducing flowgraphs are different from the rules for reducing

diagrams of circuits. Part of the preceding summary was therefore devoted to explaining that the same terms were used in flowgraphs and in circuit theory, but the meanings were different.

Method. Students enrolled in the course Introductory Systems and Design served as Ss. Experimental and control groups were designated randomly, subject to the restriction that the groups were matched with respect to mathematical aptitude scores and divided into "high" and "low" ability strata prior to the experiment. The random division into control and experimental groups was made within each ability level, so there were four groups:

<u>Experimental</u>	<u>Control</u>
High ability	High ability
Low ability	Low ability

The experiment was conducted according to the following plan, with exactly the same programmed material and test used for both groups, except that the experimental group read a preceding "scaffold" as well.* (These materials and the test are given in Appendix C.)

Experimental Group	Read Programmed Material preceded by Summary	Test
Control Group	Read Programmed Material	Test

An attempt was made to give as little specific information in the summary as possible, since of course reading information twice (in the program and in the summary) might aid acquisition. The programmed text from which the experimental materials were taken was organized as a branching text. This organization was

*Ideally, three groups might be used, with a third group reading only the summary. A third group could not be formed because the number of available Ss was not large enough. It would have been difficult in any case to devise a method to consume the time used in reading the programmed material by the other two groups.

modified for the experiment so that more material could be covered and the difficulty might be less. Smaller, linear segments were derived from large branching segments in the original text, and a fill-in question was given at the end of each segment. This fill-in question also was designed to permit later checking to see whether students did actually read the complete selection of material and whether there were conceptual difficulties in the presentation. After each fill-in question, the correct response was given at the top of the following page.

Results. Error scores on a post-test covering material presented in the programmed segments were obtained. The booklets were checked to ascertain whether all Ss had completed reading the programmed material, and it was found that approximately half the persons in the experimental group had not entirely completed the booklet, while about one-third of the persons in the control group had not completed the booklet. Tests of persons who had not completed 21 or more of the 24 programmed segments were discarded. The mean error scores for the remaining persons are shown in Table 1 below.

Table 1. Error scores on posttest

	Control Group	Experimental Group
High Ability	4.92	4.87
Low Ability	4.78	5.62

These means do not differ significantly, and indeed, with the exception of the low-ability -- experimental group mean, they are practically identical.

Discussion. The results indicate that a preliminary review, designed to provide an ideational scaffold and particularly to circumvent confusion between flow-graphs and circuit diagrams, apparently had no beneficial effect. Furthermore,

since more of the experimental group Ss were unable to complete reading the programmed materials, in terms of efficiency the preview is a hindrance -- more time is required for reading and there is no corresponding increase in performance. The persons who did not complete reading 21 or more of the 24 segments obtained much lower scores on the test, as one would expect, and this suggests a direct relationship between the number of programmed segments read and the amount learned. Thus it appears that time spent reading further segments rather than reading the preliminary summary would have been beneficial. The preliminary summary did not help those who were able to complete the programmed booklet, and actually prevented others from completing the booklet.

As far as this particular subject-matter is concerned, then, a preliminary review does not appear to be helpful. Since the review was designed particularly to combat hypothetical interference generated by the similarities in definitions and rules previously learned for circuits and the new definitions and rules to be encountered with flowgraphs, there is also some suggestion that preliminary warnings and discussion may not counteract interference. This suggestion should be viewed as a very mild one for several reasons: (1) The existence of interference with this material has not been experimentally demonstrated; its existence is an assumption. (2) With so little flowgraph material actually covered (what could be read in 30 minutes), the amount of material might have been insufficient to generate such interference; (3) the particular review presented may not have been a very good one -- perhaps with a different kind of preview, some help would have been obtained; (4) other investigators have found no immediate benefit from a preview, although they have found benefits when delayed tests were given. This effect could not be tested in this experiment. (Ausubel & Fitzgerald, 1961)

It should be borne in mind that the convenience and utility of a review section, written in conventional format and accompanying a programmed text,

might warrant inclusion of such reviews even though they do not increase immediate learning. When programmed materials are used in conjunction with an actual course requiring students to review for examinations, the reviewing process is burdensome if only the programmed notes are available. For other purposes, then, one might wish to include such reviews. The fact that a review given preceding the programmed material does not appear to be helpful does not necessarily imply that reviews inserted at other points or at the end would not be helpful. This is a matter for future experimentation.

Experiment III. Learner-determined alternatives in a Branching Programmed Text.

The Problem. The problem is to compare alternatives at branch-points in a text on flowgraphs formulated by the learner with alternatives supplied by an instructor (author).

Background. In branching programmed texts, alternatives provided at the branch points are those considered appropriate by the author. There has been little study of whether furnished alternatives are the relevant ones in the learner's view. If these two sets of alternatives do not coincide, a branching text would be defeated as far as its main goal is concerned: to provide alternate linear programs for learners of different capacities. It is frequently overlooked that a branching text, if it is to be adequate, must provide a high reinforcement rate in remedial branches or students will be blocked from proceeding.

In order to teach flowgraph theory (an outstanding recent development in systems engineering), Huggins (1961) prepared and used two branching booklets on flowgraphs and two similar booklets on operator flowgraphs and signal generators. Feedback from trials of the booklets in two prior years has caused revision of the booklets, but in some respects the trial has been limited. Paths taken by the students through the booklets were recorded, and pass-fail rates noted for the various branch-points. This gave a good notion of where trouble is, but not necessarily what steps should be taken to remedy the trouble. It seemed likely that some conceptual difficulties experienced by the students would not be anticipated by the author, and the branching booklets, as presently used, could not reveal them.

Therefore, the branching booklets on flowgraphs were dissected into sections, and a linear sequencing followed. Instead of presenting the equivalent of a multiple-choice question at the end of each section (as was the case when the booklets were in the branching format), free-response questions were given.

The purpose was to force students to construct answers so these answers could be compared with the alternatives previously formulated by the author.

Method. The programmed material was used with two groups of students. One group of 5 students were individually "tutored through" both booklets. These 5 students presented contrasts in ability level. Two were above 700 on CEEB mathematical aptitude scores, and the remaining three were close to the lower cut-off point in the 500-600 range. That is, E gave S segments one at a time, and after reading a segment, S wrote an answer to the question at the end of the segment. E inspected the answer. If it was incorrect, E attempted to discover by questioning the S face-to-face what his misunderstanding was, and kept notes on this. Then E ascertained that the point was clearly understood before S proceeded to the next segment, so that each segment could be tested as independently as possible.

A second group of students, the entire class in Introductory Systems and Design, constructed answers to the first three segments in the second flow-graph booklets. The segments were arranged in five individual packages (see Appendix D). After an answer was written down, the student put aside the segment and looked at the next segment. Here the correct answer for the preceding segment was given and explained. This was an attempt to keep results from various segments as independent as possible of one another. After the explanation, space was provided for students to comment upon the difficulties they were experiencing and to note matters that were still unclear.

Results. Small Group. The constructed answers were tabulated. These tabulations are reproduced below for Booklets I and II.

Table 1. Summary of Analysis from Individual Tutoring of 5 Students through ATT-1 - Adaptive Teaching Text on Flowgraphs*

Segment Number	No. of Students with correct answer	Interpretation of Errors for Students who fail to get correct answer on first trial
1	5	
2	3	1 - signs not noticed 1 - missed idea that transmittance of branches in cascade is the product of the branch transmittances
3	1	3 - considered only branches coming into a node 1 - missed idea that branch directions are implied by arrows
4	0	5 - missed idea that transmittance of a self-loop is affected twice by a sign change
5	1	1 - got loops but missed paths 1 - got loops but equates $x_2 - x_3$ to $x_3 - x_2$ 1 - got loops and one path 1 - got only one loop, 3 open paths from 2 to 3, 4 open paths from 1 to 4
6	1	1 - got 5 open paths transmittance correct 3 - got paths correct but wrote separately transmittances for each path
7	0	3 - did algebra correctly but failed to combine branches into a single graph 1 - algebraic mistakes does not know how to translate algebraic expression into graphical terms 1 - failed entirely

*The experimental materials are available upon request from the author.

Table 2. Summary of Analysis from Individual Tutoring of 5 Students through ATT-2 - Adaptive Teaching Text on Flowgraphs*

Segment Number	No. of Students with correct answer	Interpretation of Errors for Students who fail to get correct answer
1	3	1 - thought fourth graph wrong 1 - confused about node elimination and directions of arrows on self-loops
2	5?	This problem was exceedingly difficult and 3 students were unable to write anything at all without further help. This segment was revised for the later group test, therefore. The same problem was used, but asked differently.
3	2	3 - could not write anything without further explanation
4	2	1 - did not get self-loop 1 - could not start without help 1 - got correct answer by wrong route
5	5	1 - said Yes to "Yes - No" question
6	4	1 - apparently still does not understand how branch transmittances add at node
7	0	5 - this segment was absolutely impossible for all. Some students required two hours of work to get this segment, and lengthy explanation. Needs drastic revision
8	1	2 - took nodes in another order and computed 1 - showing negative transfer from self-loop transmittance 1 - careless mistake (misplaced a loop)
9	1	4 - failed to notice only one-way branches

*The experimental materials are available upon request. The first 3 segments correspond to the materials used with the large group.

Table 2 (continued)

Segment Number	No. of students with correct answer	Interpretation of Errors for students who fail to get correct answer
10	5	
11	5	
12	1	3 - miscounted pairs 1 - forgot triple
13	5	
14	1	3 - forgot extra b and d loops 1 - trouble expanding all at one time

Inspection of these tables confirms the author's experience in the tutoring session; there is remarkably little difference between students of various ability levels. Many suggestions, too voluminous to reproduce here, were obtained in the face-to-face discussions. For instance, it is possible for a student to produce a correct answer at some points even though he does not fully understand the material.

Large Group. The analysis of constructed answers is reproduced below, section by section in Table 3.

The insights gained from this analysis were startling. These are noted in the analysis in detail. In some cases fairly infrequent mistakes were especially revealing.

The constructed answers have been compared with the answers offered by the author. These comparisons are shown in Table 4.

The conclusions from this table are obvious. The "Yes - No" choices appear not to be optimal because they obscure the sources of the learners' difficulty. Where more specific alternatives have been provided by the author, they tend to correspond fairly well with students' errors. In some cases these specific errors appear to require more than three alternatives.

Discussion. Working with two different sized groups and under face-to-face conditions vs. a non-interactive condition produced essentially two different kinds of feed back. In talking directly with students, a conceptual difficulty can be cleared up at times without the instructor's being aware of what produced the difficulty in the first place. That is, if S produces a "wrong" answer, E's most likely reaction to this is to repeat and amplify the material in the segment. It is less that the student's conception is changed than that it is abandoned. It is extremely difficult for E to simultaneously observe both his own behavior and the student's behavior and to isolate the crucial portion of

Table 3. Analyses of Group Responses

All booklets were collected, and a detailed record prepared of every student's response at every choice point. The responses were transcribed verbatim separately for each choice point, so that it was possible to look for patterns in the responses. Without reproducing here all of the responses in detail, we give below the chief conclusions from an examination of the responses.

Section I, page 4. Four sub-sections.

Sub-section 1. The error rate was very low ($3/72$). This example was apparently well understood.

Sub-section 2. The graph presented is an incorrect reduction. Twenty-three of the students thought it was correct. Forty-two said the graph was incorrect, but the stated reasons for the incorrectness are not valid or are not clear. Only 17 stated clearly why the graph is wrong. Overall the confusion appears to stem from the transmittance of a self-loop -- a concept not yet defined by itself. This suggests that self-loops should be avoided until they are able to be treated separately.

Sub-section 3. About 15 students say this is wrong, when it is actually correct. Of the remainder, although all say the graph is correct, there is serious doubt about the bases of their conclusions in view of the results from sub-section 2. The same errors that are being committed under 2 are undoubtedly being committed here.

Sub-section 4. Almost all of the students who say this graph is correct also say the second graph is correct, so it appears their conclusion is based on incorrect premises. The majority are making an incorrect calculation for the output at node 4 because they do not know what the transmittance of a self-loop is.

Section II, page 34. Here students were given an opportunity to comment on the graphs given in Section I, page 4, after they have examined the correct answers. Their comments are like the following: "I did not consider the equivalence of signals at each node." "I was at first unclear as to the significance and meaning of the term transmittance. If the signals x_1 had been introduced in the explanatory material the meaning may have been clearer."

In general, the students' comments confirm conclusions reached by inspecting their answers to Section I, page 4. The self-loop is a source of difficulty, and also they appear not to understand the "equivalence" of one graph to another in terms of equivalence of signals at retained nodes.

Section II, page 4.

Three sub-sections. The error rate on this series is lower than the last series. The same conceptual difficulties are occurring, however, for those who do answer incorrectly. It is clear that several points must be stressed and reiterated at this point: (1) arrows on self-loops may go in either direction (not stated explicitly previously); (2) branches in series have transmittances multiplied; (3) that graphs are equivalent in terms of retained nodes; (4) how the transmittance of a loop is determined. In the revision some preceding examples will be given, illustrating the process of calculating the input and output node by node, and the above points repeated.

Section III, page 2.

Again, students were given an opportunity to comment on what was unclear about the preceding set of examples if they felt that they still did not understand it. Only four students commented, and these comments reiterate the four points made above in connection with Section II, page 4.

Section III, page 3.

Here 21 of the students get the wrong answer. The two most prevalent mistakes involve using the reciprocal as input (instead of the complement), and

it is easy to see how one could fall into this pattern. The second mistake involves getting a factor of 2 in the answer. Why this happens is not entirely clear, but apparently stems from a misunderstanding that all branches emanating from the same node carry the same signal. Another example of the same concept will be added, since the error rate here is rather high.

Section IV, page 2.

Comments at this point make it clear from where the factor of 2 was coming in Section III, page 3. It should be emphasized that the conceptual mistake leading to formulations with a "2" in them was impossible to analyze before the students' written comments of this section were studied. It appears that they are subtracting outgoing branches from incoming branches to get the signal value of a node. This is entirely wrong, of course, because outgoing branches have no effect whatsoever on the signal at a node. Since several students appear to have "extended" the definitions to come up with this result, this can be specifically warned against and the definition of signals at a node reviewed.

Section IV, page 3.

Only 13 students were capable of this derivation. It appears that they carry along in algebraic terms the nodes. This is a correct procedure, but in pushing the problem through to arrive at a general formulation, the nodes may be eliminated. This they fail to do. It appears that this problem is very poorly stated. Transmittance (output over input) needs to be defined. Then it needs to be pointed out that the branches with unity transmittance do not affect the result, and therefore the easiest way to approach the problem is to assume that the input signal is one.

Section V, page 4.

Only 16 students were able to carry through this derivation. Most were able to do only the first step, which was almost trivial in view of the hint given.

Since this question, as originally asked, was a "yes - no" type, it would be easy for students to answer "yes" without actually bothering to carry through the steps of verification. Since this appears to be impossible for most, this question should be broken down into a series of small questions with hints given at each step. Then after this, another question like it should be given with fewer hints to let the students practice. The students' comments (Section V, page 5) reveal that they do not know what the second step in the reduction should be.

Table 4. Comparison of Responses provided by Author
with answers constructed by students

Segment	Alternative provided by author	Students' "alternatives"
1	error no error	It is clear here that the alternatives provided are inadequate, because many students said that 4th graph is wrong even though it is correct. A specific branch is needed for each choice -- 1, 2, 3; 1, 2, 4; etc.
2	error no error	Again it is recommended that more specific choices be provided.
3	$y = x$ $y = (1 - t)x$ $y = 2x$	$y = (1 - t)x$ (correct) $y = (1/t)x$ $y = 2x - tx$ No student made errors to correspond with the two incorrect alternatives previously provided.
4	$A = 1$ $A = 1 - t$ $A = 1/(1 - t)$ (correct)	$A = 1(1-t)$ correct $A = 1$ $A = 1 - t$ $A = t$ $A = 1 + t$ Here students produced the four wrong answers above with about equal frequency. The author correctly anticipated 2 of these, but since the others appear to be prevalent, they should be included also.

table 4, (continued)

Segment	Alternative provided by author	Students' "alternatives"
5	correct	Again, with only these two choices available, students can easily go on without understanding the material. It is clear that 80% of the group cannot derive the correct result independently. The problem needs to be broken into several steps.
	incorrect	

the behavior of both.

In developing a programmed text initially, feedback is necessary to indicate how difficult the material is. This feedback, with branching texts, cannot be entirely obtained from a record of students' paths through the volume. With two or three choices available, there are many students who pick the right path by chance and also many who pick it for the wrong reasons. It is also clear that many students can complete the route without actually understanding the material. Face-to-face interaction with students gives some idea of the actual difficulty of segments and some hint of what to do to reduce it. It thus serves as a first-refinement procedure.

After material has been developed as described above, further refinements are possible through trying out sections of the material on a large group. The difficulty of the material must be low enough at this stage in development so that students can proceed through it. This is accomplished by prior work with small group. Error patterns can display themselves with a large group in a way that is impossible with a small group of five. With the small group, one deviant response is 20% of the group.

The observation of the large group appears to be an ideal method for framing alternatives. The experience here suggests that about three persons making the same mistake is enough to warrant inclusion of the indicated alternative. For one segment (see Table 4) five choices appear to be required. Since this number is too large to be practical for a branching text, it is not clear how best to handle such a situation. One possibility would be to combine errors into groups that appear to involve the same misconception.

Inspection of Table 4 suggests that (1) specific choices, rather than "Yes - No", be provided; (2) for these problems, student monitoring of alternatives is very revealing. The overlap is rather small between students' and author's alternatives.

Conclusions. This study clearly indicates the necessity for obtaining highly detailed feedback when branching texts are being developed. There seems to be no reason why this kind of program cannot be monitored by learners in exactly the same manner as linear programs. It is hard to see what advantage accrues from branching in this case, because to monitor the program a linear format is necessary. It would be easier to have material follow in sequence with alternatives presented:

Alternative 1 - see next page

Alternative 2 - skip one page

Alternative 3 - skip two pages

These skips could be rotated, if it seemed desirable, so that the amount skipped did not disclose the correct answer.

Experiment IV. The Efficacy of Written Responses vs. Reading Only in a Linear Program on Digital Computer Programming.

Purpose.

The purpose of this experiment was to determine whether learning of programmed material dealing with digital computer programming would be enhanced by students' explicit writing of answers to questions vs. reading of the same material with questions and already-formulated answers.

Background.

To date results from experiments contrasting written responses with covert responses or mere reading of examples have generally been negative (Review of Educational Research, December 1961). It appears that there is no advantage in writing responses with few exceptions. The exceptions seem to be related to four factors: (1) Writing appears to be helpful with long programs; (2) writing may aid retention, measured by delayed tests, even when no advantage is found with immediate tests; (3) writing may be helpful if the material is difficult, and (4) writing may help if the learning task involves writing in a non-incidental way.

The first factor, length of program, could not be investigated because experiments had to be confined to one class period. For the same reason, retention could not be investigated in a strictly controlled manner, although a delayed test was used. It was felt, however, that explicit writing of responses might be helpful because the material is generally conceded to be difficult for beginners and also because writing programs appears to involve writing directly, rather than incidentally. Each detail of a hand-written program is very important, and a "clerical" error will prevent a program from running. Also programming is difficult in some aspects because rules run directly counter to long and well-established habits. For instance, in FORTRAN programming multiplication must be

indicated explicitly by a "*" and letters written in sequence do not imply multiplication as they do in algebra. Or, in indicating terms in a denominator, one must be careful to include all factors within parentheses, or only the first factor will be used as a divisor. Thus

$$\frac{3.2}{1.6 * 7.1} \text{ in algebra}$$

must appear in FORTRAN as

$$3.2/(1.6 * 7.1)$$

with parentheses around the terms of the denominator. If parentheses are omitted, 3.2 will be divided by 1.6 and then the quotient will be multiplied by 7.1 (rather than divided). These changes in notation result in many errors by beginning programmers, and it was thought that explicit practice, by writing responses, would help reduce errors of this kind.

Method.

The subjects in this experiment were students enrolled in the course "Introductory Systems and Design" at The Johns Hopkins University in 1962-63. The subjects were divided into five strata on the basis of mathematical aptitude scores obtained from college records, and within each stratum students were randomly assigned either to a control or experimental group.

Two booklets to teach FORTRAN arithmetic were prepared. (These are shown in Appendix E .) The booklets were identical except that the version used with the experimental group required students to write explicit answers to questions in a margin provided for that purpose. After writing an answer, the student could turn the page and a correct answer would be displayed directly opposite the answer he had previously composed. He could thus ascertain immediately whether or not his answer was correct, and if not, why. The booklets read by the control group presented exactly the same examples, with answer following immediately, and the student read through both the questions and answers but did no writing.

A test (see Appendix E) covering the material presented in the booklets was given immediately after work with the booklets was complete. A second test, given unannounced 48 hours later, was designed to be as much like the immediate test as possible (see Appendix E).

Results.

The total number of errors made on the immediate test, summarized according to the five pre-determined ability strata, is shown in Table 1 below.

Table 1. Errors on Immediate Test

	Exptal.	Control	Difference
Stratum 4	18	9	- 9
" 3	21	20	- 1
" 2	20	26	+ 6
" 1	32	21	-11
" 0	<u>32</u>	<u>25</u>	- 7
Total	123	101	

The total number of errors made by the control group (no writing) is 101, and is less than the number of errors made by the experimental group, 123. The experimental group studied booklets requiring writing. The error scores were subjected to an analysis of variance, shown in Table 2.

Table 2. Analysis of Variance of Error Scores

Source of variance	d.f.	SS	MS
Exptal. vs. Control groups	1	5.29	5.29
Strata	4	28.30	7.07
EC x S	4	10.26	2.55
Error (residual)	90	372.90	4.14

The F-ratios of none of the above are significant.

The small difference between the two groups which favors the control group is not statistically significant. Also Table 2 shows that there is no interaction between ability-level and treatment.

A second 16-item test, slightly altered in content and arrangement but covering exactly the same type and number of concepts, was administered unannounced 48 hours later. Students were asked to indicate whether or not they had studied the material in the meantime, and those who admitted studying are omitted from the variance analysis in Table 3. The analysis reveals that a significant difference ($P = 0.05$) exists between the two test administrations. Students, whether in the experimental or control group, improved their scores on the second test, even though they had not studied. All other factors do not attain statistical significance. In particular, there is no interaction between groups and test-retest, which suggests that the improvement from one testing to the next occurs independent of the experimental treatment.

Test-retest differences are commonly found even when exposure to relevant material is much better controlled than in the present experiment (here students may have "rehearsed" the material mentally, even though they did not consult any outside source). Also, test-retest differences are found when no experimental procedure is incorporated before or between tests (Entwisle, 1961). These differences are often positive for bright students, and negative for below-average students. A positive difference is observed here, and of course all students in the present group would be considered "bright".

The analysis of variance summarizes the test-retest results. There are 8 students in each ability-treatment stratum, because some students were not present on both occasions, and those who admitted studying the material were eliminated.

Table 3. Analysis of Variance -- Scores on First and Second tests
(Raw scores are number of errors)

Source of variance	d.f.	SS	MS	F
<u>Between Individuals</u>	79	400.09		
Exptal. vs. Control	1	6.80	6.80	
Strata (ability)	4	34.56	8.64	1.72
EC x S	4	7.41	1.85	
Residual (error bet.)	70	351.32	5.02	
<u>Within Individuals</u>				
Test ₁ vs. Test ₂	1	9.50	9.50	4.87*
T ₁ T ₂ x Strata	4	0.72	---	
T ₁ T ₂ x EC	1	0.01	---	
T ₁ T ₂ x EC x Strata	4	1.72		
Residual (error with.)	70	135.05	1.92	

These analyses indicate that apparently explicit writing of responses did not increase immediate or delayed recall of the material on programming. It should be emphasized that even if the delayed test had indicated a positive outcome in terms of the hypothesis, this outcome could have been regarded as suggestive evidence only since of course uncontrolled factors could have led to this outcome. Krumboltz and Weisman (1962) did find explicit responding better for a retention test, although not for an immediate test.

Discussion.

Presenting experimental material and a test within one class' period imposes severe restraints on an experiment such as this one. Here it was necessary to limit study to 30 minutes, and a test occupied the remaining 20 minutes of one class period. The stringency of these time limitations is even more severe than one might imagine; because in an experiment of this sort the time limits are determined by the slowest person in the class. A student not finishing the booklet or the test has to be discarded from the experiment, and

since discards unbalance the design and also reduce the likelihood of being able to detect a treatment-difference, every effort is made to ensure all subjects complete the experiment. This implies that the total amount of material that can be presented is small by practical criteria.

This experiment, then, corroborates the findings of most other experiments on response mode: explicit responding does not appear advantageous compared to implicit responding or to mere reading of material. This finding thus appears to generalize to digital computer programming, a subject which, for various reasons, might have been thought to be learned more easily when practice in writing programs was included.

It should be emphasized that the main conclusion is restricted to a very short segment of material, and resources at our disposal did not permit assay of more realistic amounts of material. It may well be that in long programs explicit responding is helpful if only because it forces the learner to be continually active and so maintains his attention level. In general, it would be impossible to teach digital computer programming without requiring writing at some points in the learning process because by the time a student is capable of writing short programs he must write programs--he cannot possibly keep in mind the necessary statements and their sequencing without external cues. The task required of a programmer is actually a problem-solving task, and for the same reasons that a mathematician or chemist finds pencil and paper indispensable in problem-solving, a programmer also must write. This aspect of the task, which was too advanced for beginning students, was not included in the present experiment. It is mentioned because although writing may be of no help in the early stages of learning programming, it is very difficult to imagine anyone being able to learn more advanced stages without resorting to writing.

Bibliography

- Ausubel, D. P. & Fitzgerald, D., The role of discriminability in meaningful verbal learning and retention. J. Educ. Psychol., 52, 266-274, 1961.
- Deese, J., The Psychology of Learning, McGraw-Hill, New York: 1956.
- Entwistle, D. R., Interactive effects of pretesting. Educ. & Psychol. Measmt., 21, 607-620, 1961.
- Hall, J. F., Retroactive inhibition in meaningful material. J. Educ. Psychol., 46, 47-52, 1955.
- Huggins, W. H., "Signals and Circuits (Adaptive Teaching Text, ATT-1)" and "Transformations and Reductions of Signal Flow-Graphs (Adaptive Teaching Text, ATT-2)", The Johns Hopkins University, Baltimore, Md., 1962.
- Krumboltz, J. D., and Weisman, R. G., The effect of overt vs. covert responding to programmed instruction on immediate and delayed retention. J. Educ. Psychol., 53, 89-92, 1962.
- Osler, S. F. & Fivel, M. W., Concept attainment: I. The role of age and intelligence in concept attainment by induction. J. Exper. Psychol., 62, 1-8, 1961.
- Osler, S. F. & Trautman, G. E., Concept attainment: II. Effect of stimulus complexity upon concept attainment at two levels of intelligence. J. Exper. Psychol., 62, 14-23, 1961.
- Stephens, J. M., Educational Psychology, Henry Holt, New York: 1958.
- Woodworth, R. S. & Schlosberg, H., Experimental Psychology, Henry Holt, New York, 1954.

Appendix A
Materials for Pilot Study on
Retroactive Interference

Booklet on Computer Programming
(Neutral Material)
for Pilot Study

You will write programs in a language called "FORTRAN". IBM computers "understand" FORTRAN, and FORTRAN is a language very much like algebra. For instance,

$$5 + N \text{ (in algebra)}$$

is

$$3 + N$$

in FORTRAN. All the arabic numbers (0 through 9) are available, as well as the English alphabet and symbols such as +, -, /, etc. There are no Greek letters, and all letters are written in capitals (upper case). Thus, if you had

$$3 + n \text{ (in algebra),}$$

in a FORTRAN translation it would appear as

$$3 + N$$

You are fortunate, because aside from facts you already know, there is only one new concept in programming. This concept is addressing. The computer carries out your instructions by using the addresses of quantities you call for. This is, when you mention A in an equation, the computer takes this to mean: "address where A is located". If you want the computer to add 3 to A, when A is located at address 10,000 and 3 is located at address 2,000, the computer tells itself to add what is stored at address 2,000 to what is stored at address 10,000. For FORTRAN language that you write is translated by the computer so that when you say "Add 3.0 and X", the computer adds what is stored at X's address (which may be 5.1) to what is stored at 3.0's address (which is 3.0). Although you do not have to be directly concerned with machine addresses, it is helpful to realize that the computer eventually works with addresses, particularly in working with the equal sign in FORTRAN. Every time you see an equal sign you

Different models of IBM computers "understand" slightly different versions of FORTRAN.

instruct the computer: Replace what is on the left of the equal sign by what is on the right. For example, if you say

$$A = B$$

the computer will replace the value of A by the value of B. It takes what is stored at the address of B, and moves it to the address of A. What used to be stored in A is lost. This is known technically as non-destructive read-in (what used to be stored at A is now replaced by what is stored at B), but what used to be stored at A is lost. The computer resembles a tape recorder -- once something is recorded you can play it over and over (you can call for B as many times as you like), but if you record something over a previous recording, the first recording is lost (the value of A is lost when the value of B replaces it).

This feature of the machine causes a basic change in the meaning of an equal sign. The equal sign means: Replace what is on the left by what is on the right. This change in meaning allows statements like the following

$$M = M - 1$$

which says "Replace M by M - 1".

Each time you replace a quantity on the left of an equal sign with a quantity from the right, the left quantity is lost.

Also, when you say

$$X = Y$$

you are saying "Put Y where X is now", and so all manipulations must be made on the right side. For instance,

$X + 1 = Y$ is wrong -- you must write

$$Y = X + 1$$

On the left of any equal sign in FORTRAN appears a single quantity. You can say

$$N = M + 1 - L/I$$

$$J = K/3$$

where on the left of the equal sign is the name of one variable -- all operations are carried out on the right. We will discuss this more thoroughly later.

It is as though the computer had inside it many pockets. Each variable and constant has its own pocket, and every pocket has a name. For variables, the name of the pocket (say "M") is different from what is contained in the pocket (some number). For constants, the name of the pocket (say 3) is the same as what is contained in the pocket. A pocket can contain only one numerical quantity at a time. If you say

$$Y = A + B$$

the computer goes to A's pocket, looks in and writes down the numerical value currently contained in A but does not disturb A. It does the same for B. It then adds A and B and replaces what used to be in Y's pocket by the sum $A + B$. Thus A and B are not changed, but what used to be in Y's pocket is lost.

The basic IBM 1620 computer has 20,000 digits of storage, and many laboratories have multiples of this (either 40,000 or 60,000 units of storage). Each storage unit can hold one decimal digit. In each of the storage units the computer can store a 0, 1, 2, ..., or 9. Furthermore, the computer can hold only digits 0 through 9. It holds other symbols by using a code made up of decimal digits. For instance, it takes two digits of storage to represent an A - A is 41. All other alphabetic and special characters are similarly represented by a two-digit code. Translations into numeric code are automatic when you use FORTRAN.

The computer automatically translates your FORTRAN program into machine language. Machine language is the only language that the computer can use when it is actually executing your problem. Machine language consists of nothing but the digits 0 through 9. For instance, a machine language instruction telling the computer to add what is in cell 2,000 to what is in cell 10,000 looks like this:

"Code for Add"	Address of N	Address of 3
21	10000	02000

If you had to write in this code, you would have to look up the code for every operation (addition, etc.) and then keep track of what is stored at all various addresses. (This is the tedious process that was required in the early days of computers.) FORTRAN is very powerful, for if N is at 10,000 and 3 is at 2,000, you do not need to know even where they are located. You merely say in FORTRAN:

$$N = N + 3$$

The computer keeps track of all addresses for you when you use FORTRAN. For complicated operations, machine programming is very tedious, but with FORTRAN you write in almost the same language as algebra.

As a matter of fact, the FORTRAN language and other computer languages are rather recent. It is estimated that it took 20 man-years of work to develop FORTRAN. It is an abbreviation for "Formula translation", and was designed to be as like ordinary algebra as possible.

Thus, preparing a program is a two-step operation: (1) you write the program in FORTRAN and get it on cards; (2) the computer takes your FORTRAN cards and produces another set of cards, the object program, which will actually solve your problem. Once you have the object program, you can load it directly into the computer and run it as many times as you wish.

You can write in a language close to algebra (viz. FORTRAN), but the machine must first make a machine-language program from your FORTRAN program. Making a correct machine language program is tedious, and the computer relieves you of this burden. Thus, part of the programming task is taken over by the computer. If your source program (written in FORTRAN) is incorrect, you will not only have to re-write the FORTRAN part that is incorrect but re-compile the entire program. Your object deck (in machine language) cannot be corrected without an intimate knowledge of the machine. So if you make a mistake your program must

be re-compiled from the beginning. This points up the need for careful checking of your original program: if you omit one comma, one parenthesis, or make any other mistake, the program will not run and the whole program will have to be translated again by the machine (re-compiled). In this respect, programming is very demanding.

The importance of desk-checking cannot be overemphasized. That is, at every step of writing a program you must be absolutely sure you are coding the instruction correctly. After you have completed the program, you will need to double check every symbol and operation again. Furthermore, after your handwritten program has been punched on cards, you will need to check that it has been punched accurately.

Psychology Systems

EXPERIMENTAL COMPONENT

Please do not open booklet until instructed to do so.

This booklet contains the **Test Booklet for Pilot Study**

When the experimenter says "Go" you may begin the test.

5217 Introductory Systems

EDUCATIONAL EXPERIMENT #2

NAME: _____

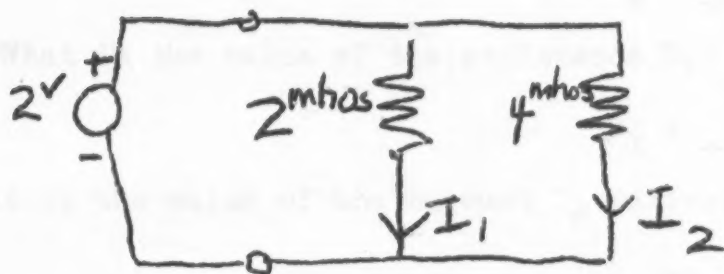
Please do not open booklet until instructed to do so.

The questions inside should be answered as rapidly as possible. If you do not know the answer, guess. DO NOT TURN BACK AND RE-WORK OR REVIEW ANY ANSWER.

Fill in blanks using selection of words given: resistance(s), voltage, parallel, node, short, series, current, branch, conductance(s), open.

- 1) Practical current sources are represented in _____ with a conductance.
- 2) A resistance or conductance in _____ with a current source may be neglected as far as the delivered current is concerned.
- 3) Two current sources in _____ may be combined into a single source.
- 4) A dead voltage source is equivalent to a _____ circuit.
- 5) A current divider circuit divides the current in proportion to the _____ of each branch.

6)



The ratio of currents I_2/I_1 in the circuit shown is

$1/3$ ☐

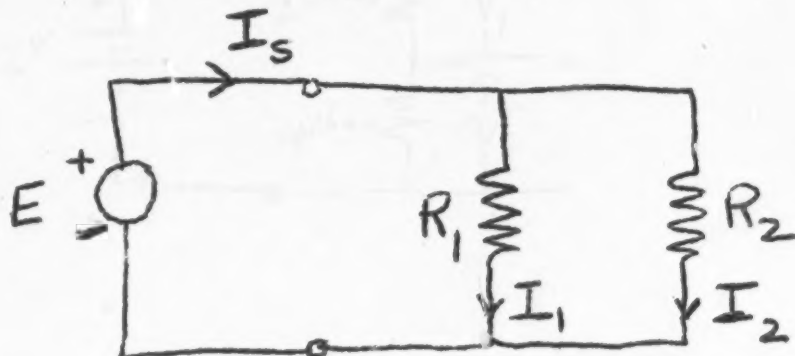
$1/2$ ☐

2 ☐

3 ☐

none of these ☐

- 7) In the circuits shown below, the value of the resistance R_2 is known to be twice that of R_1 (i.e. $R_2 = 2R_1$)



If $E = 10$ volts and $I_1 = 2$ amperes, what is the value of the current I_2 ?

$$I_2 = \underline{\hspace{2cm}}$$

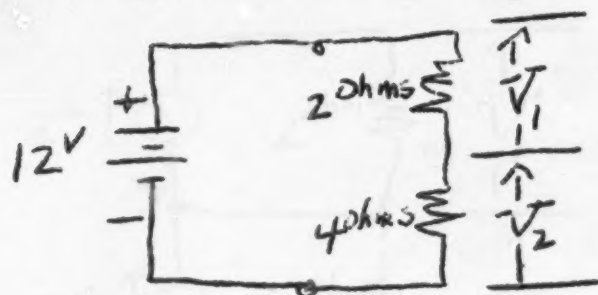
What is the value of the resistance R_1 ?

$$R_1 = \underline{\hspace{2cm}}$$

What is the value of the current I_s delivered by the voltage source?

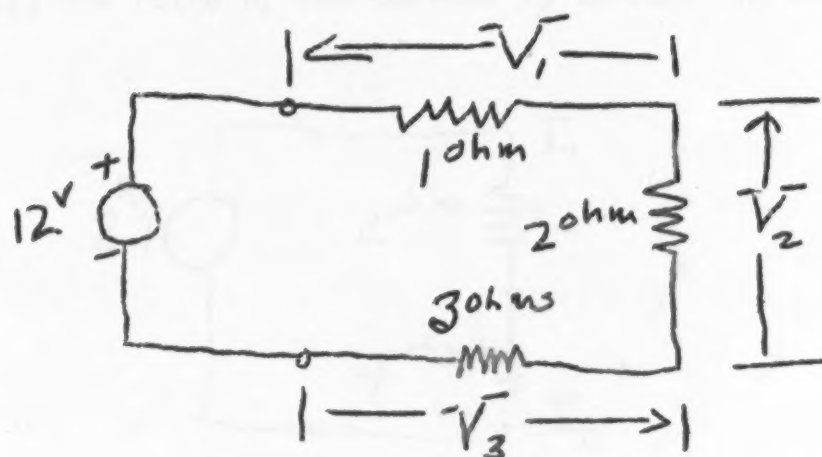
$$I_s = \underline{\hspace{2cm}}$$

8) The value of the voltage V_1 , across the 2-ohm resistance is:



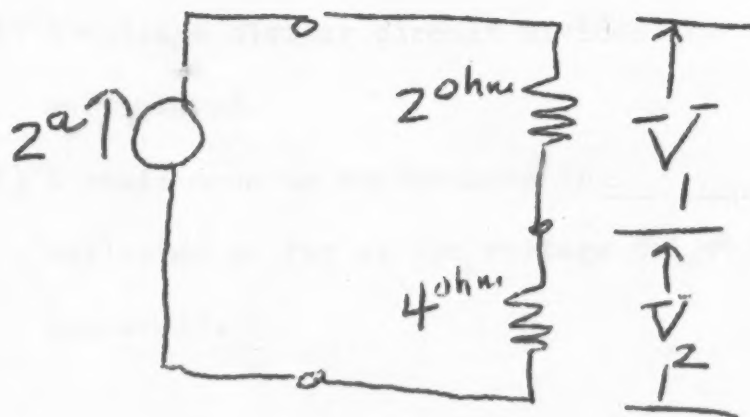
- 4 volts ☐
- + 4 volts ☐
- + 8 volts ☐
- none of these ☐

9) Given the series circuit whose resistance values are shown thereon, the value of the voltage V_2 is:



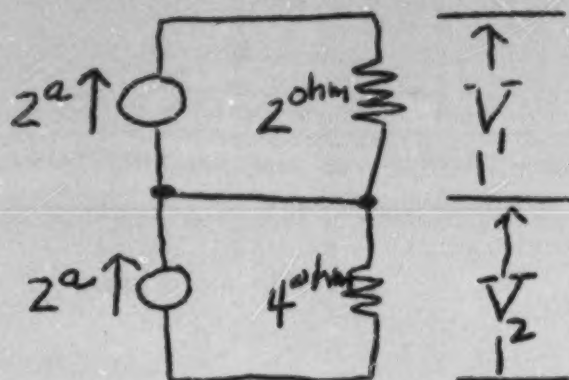
- 4 volts ☐
- + 4 volts ☐
- + 6 volts ☐
- + 8 volts ☐
- none of these ☐

10) The value of the voltage V_1 across the 2-ohm resistance is:



- 4 volts
- + 4 volts
- + 8 volts
- none of these

11)



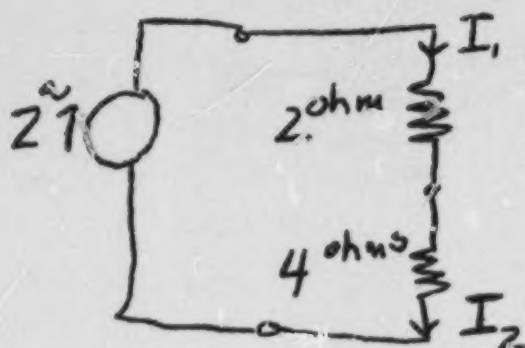
The value of the voltage V_1 across the 2-ohm resistor is

- 4 volts ☐
- + 4 volts ☐
- + 8 volts ☐
- none of these ☐

Chapter on Voltage Principles

For Pilot Study

12) The value of the current I_2 through the 4-ohm resistance is



- 2 amps ☐
- 0 amps ☐
- 2 amps ☐
- 8 amps ☐
- none of these ☐

13) A dead current source is equivalent to a _____ circuit.

14) Practical voltage sources are represented in _____ with a resistance.

15) Two voltage sources in _____ may be combined into a single source.

16) A voltage divider circuit divides the voltage in proportion to the _____ encountered.

17) A resistance or conductance in _____ with a voltage source may be neglected as far as the voltage delivered to the remainder of the circuit is concerned.

10.17 Introductory Systems and Design

Educational Experiment No. 2

NAME _____

PLEASE DO NOT OPEN BOOKLET UNTIL TOLD TO DO SO. WE WOULD LIKE YOU TO READ

THE ENTIRE VOLUME ALREADY STUDYING YOUR BOOKLET. IF YOU FINISH BEFORE YOU ARE

TOLD TO STOP, RE-READ OR **Booklet on Voltage Principles**

for Pilot Study

52.17 Introductory Systems and Design

Educational Experiment No. 2

NAME _____

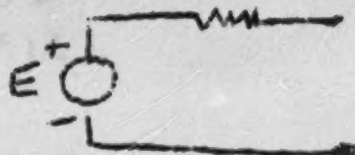
PLEASE DO NOT OPEN BOOKLET UNTIL TOLD TO DO SO. WE WOULD LIKE YOU TO SPEND
 THE ENTIRE TIME ALLOTTED STUDYING YOUR BOOKLET. IF YOU FINISH BEFORE YOU ARE
 TOLD TO STOP, RE-READ OR REVIEW THE MATERIAL.



Here there are two voltage sources in series, with polarities indicated in the same direction. WHEN TWO VOLTAGE SOURCES ARE CONNECTED IN SERIES, THE TWO SOURCES MAY BE COMBINED INTO A SINGLE EQUIVALENT SOURCE HAVING A VOLTAGE VALUE THAT IS THE SUM OF THE VALUES OF THE TWO ORIGINAL SOURCES.

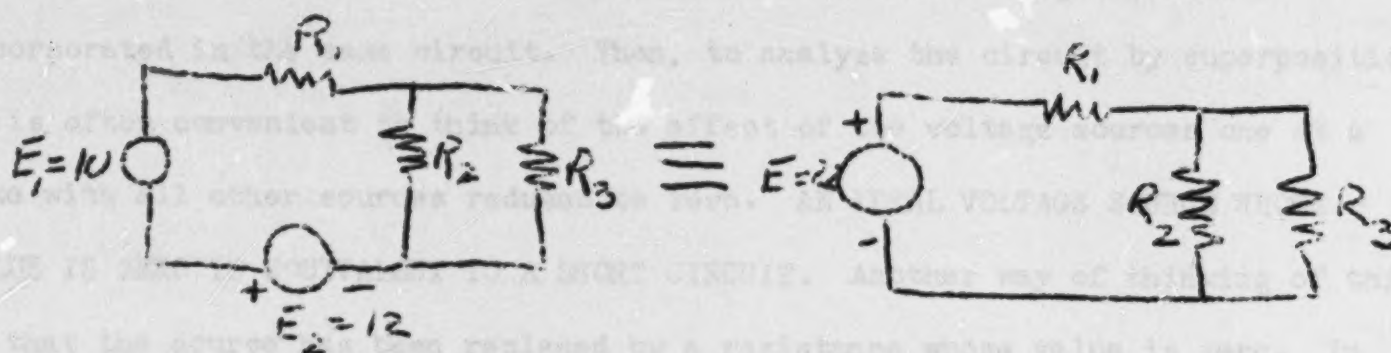
It is important to notice the polarity of the source. In the circuit on the next page, where polarities are reversed from one source to the next, the algebraic sum ($12 - 10$) is taken to specify the value of the new source.

In lecture the fundamental notion of a voltage source has been presented. These sources are "ideal"; practical voltage sources are always represented in series with some resistance R . "In series" means that the same current flows through each element under consideration.



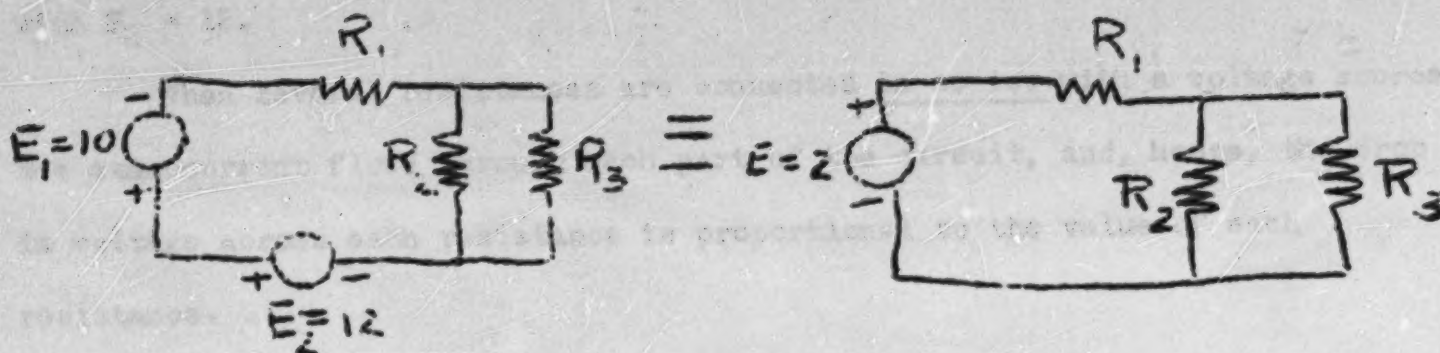
Practical
voltage
source

Very often in circuit problems you will find that a circuit contains more than one voltage source. Consider, for instance, the circuit below:

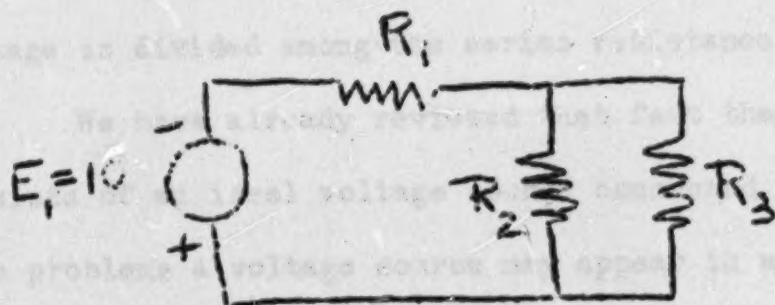


Here there are two voltage sources in series, with polarities indicated in the same direction. WHEN TWO VOLTAGE SOURCES ARE CONNECTED IN SERIES, THE TWO SOURCES MAY BE COMBINED INTO A SINGLE EQUIVALENT SOURCE HAVING A VOLTAGE VALUE THAT IS THE SUM OF THE VALUES OF THE TWO ORIGINAL SOURCES.

It is important to notice the polarity of the source. In the circuit on the next page, where polarities are reversed from one source to the next, the algebraic sum ($12 - 10$) is taken to specify the value of the new source.

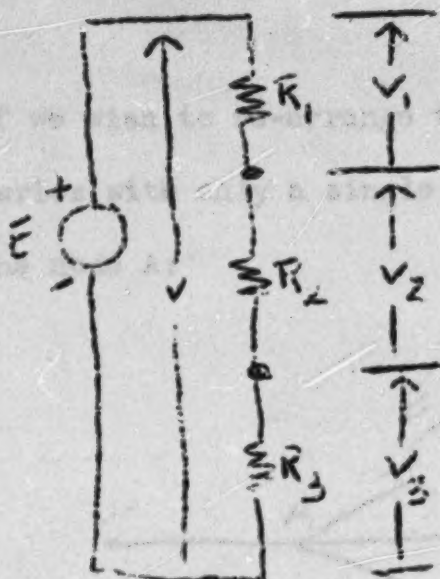


In some problems it is convenient to consider only one kind of source at a time. It is possible to have current sources and voltage sources incorporated in the same circuit. Then, to analyze the circuit by superposition it is often convenient to think of the effect of the voltage sources one at a time with all other sources reduced to zero. AN IDEAL VOLTAGE SOURCE WHOSE VALUE IS ZERO IS EQUIVALENT TO A SHORT CIRCUIT. Another way of thinking of this is that the source has been replaced by a resistance whose value is zero. In the circuit shown above, if the voltage source E_2 were reduced to zero, it would be replaced by a short circuit and the circuit would be drawn:



Of course, in this circuit a different current flows than in the circuit with $E_2 = 12$.

When several resistances are connected in series with a voltage source, the same current flows through each part of the circuit, and, hence, the drop in voltage across each resistance is proportional to the value of each resistance.



Here, by Kirchhoff's

voltage law

$$V_1 + V_2 + V_3 = V$$

and by the volt-ampere

relation for resistors

$$V_1 = R_1 i$$

$$V_2 = R_2 i$$

$$V_3 = R_3 i$$

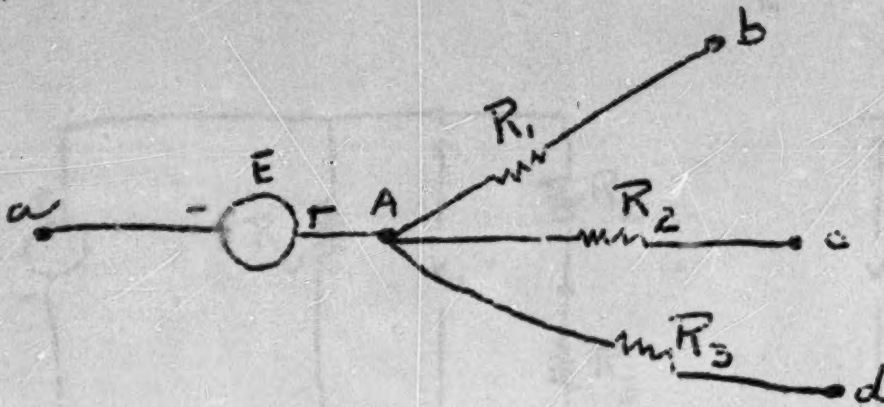
which implies that

$$V = (R_1 + R_2 + R_3) i$$

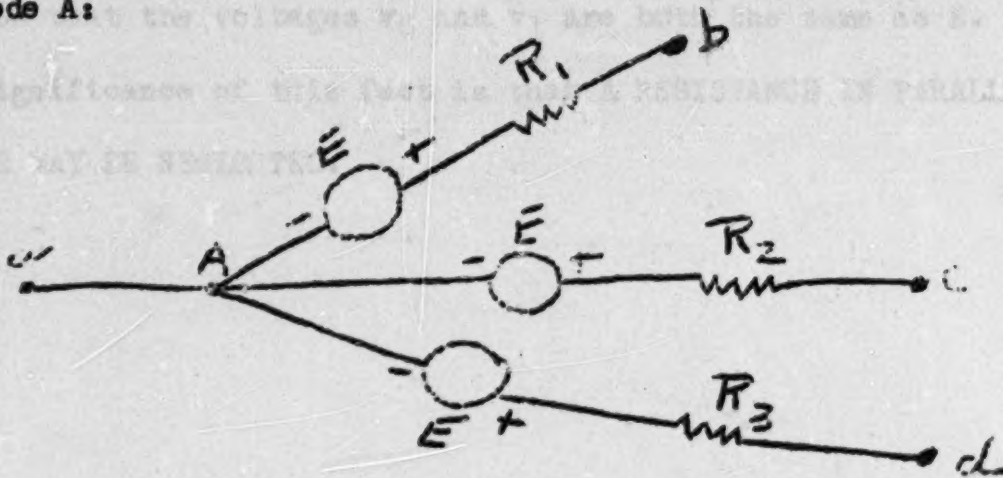
Such a circuit is often referred to as a "voltage divider" because the total voltage is divided among the series resistances.

We have already reviewed that fact that a practical voltage source consists of an ideal voltage source connected in series with a resistance. In some problems a voltage source may appear in a partial circuit connecting nodes

a, b, c, and d as below:

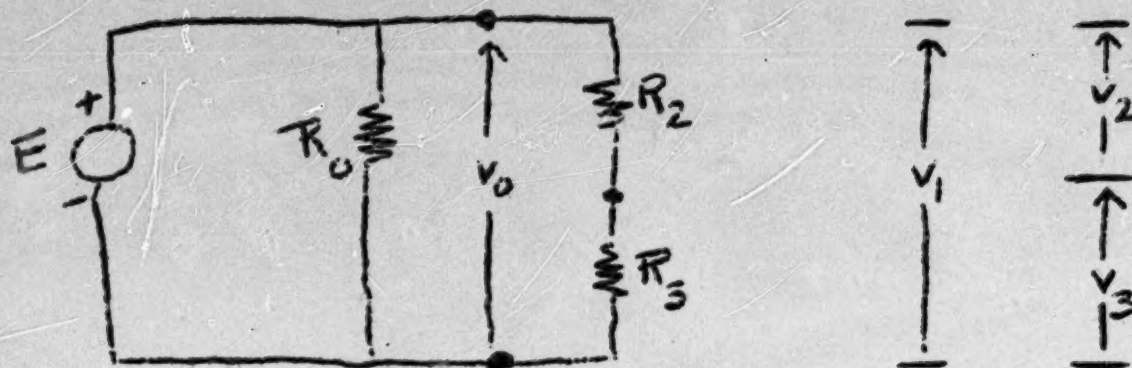


If we wish to re-arrange this partial circuit so that a voltage source E is in series with only a single resistance, we merely "push" the voltage source through the node A :



This circuit will be equivalent at the terminals a, b, c, and d to that shown previously.

We have discussed above the voltage divider type of circuit, in which several resistances in series with a voltage source effectively divide the total voltage into fractions. Consider the voltage-divider circuit shown on the next page with an added resistance in parallel.



We know that the voltages v_0 and v_1 are both the same as E .

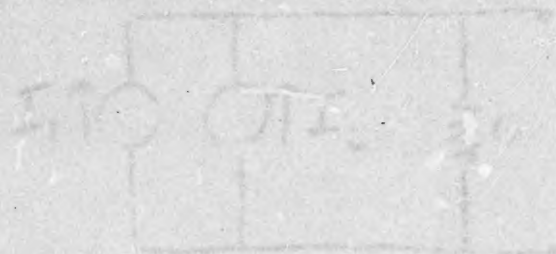
The significance of this fact is that A RESISTANCE IN PARALLEL WITH A VOLTAGE SOURCE MAY BE NEGLECTED.

You have also begun to learn recently about current sources. Practical current sources are represented in parallel with a conductance. "In parallel" means that the voltage across the elements under consideration is the same.



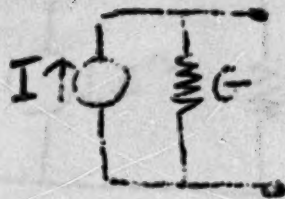
Practical
current
source

In circuit problems, often **Booklet on Current Principles** appears in a single circuit. The partial circuit is **for Pilot Study**



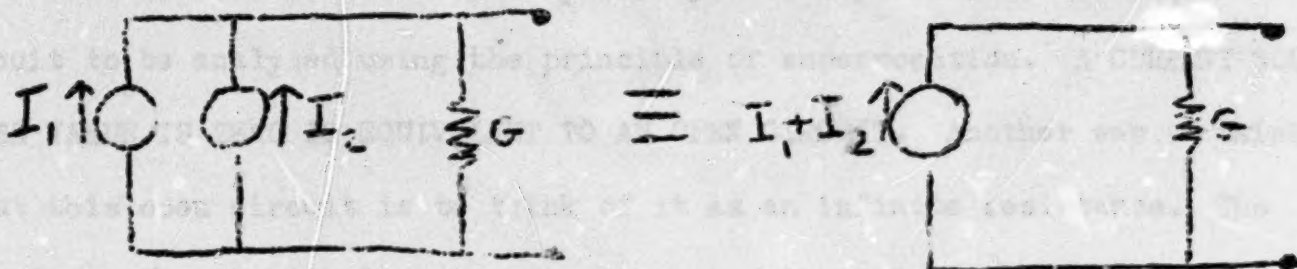
Here, there are two current sources in parallel with the arrows indicating for each the positive direction for the current produced. WHEN TWO CURRENT SOURCES ARE CONNECTED IN A PARALLEL THE TWO SOURCES MAY BE COMBINED INTO A SINGLE EQUIVALENT SOURCE HAVING A CURRENT THAT IS THE SUM OF THE TWO ORIGINAL CURRENTS. The two sources shown above have been combined into a single source supplying $(I_1 + I_2)$ amperes.

You have also begun to learn recently about current sources. Practical current sources are represented in parallel with a conductance. "In parallel" means that the voltage across the elements under consideration is the same.



Practical
current
source

In circuit problems, often more than one current source appears in a single circuit. The partial circuit below contains two current sources:

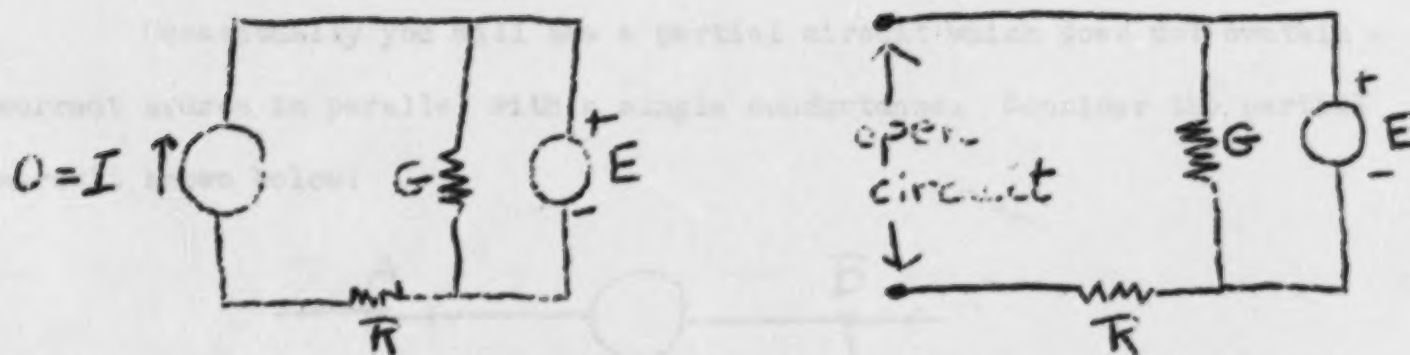


Here, there are two current sources in parallel with the arrows indicating for each the positive direction for the current produced. WHEN TWO CURRENT SOURCES ARE CONNECTED IN A PARALLEL THE TWO SOURCES MAY BE COMBINED INTO A SINGLE EQUIVALENT SOURCE HAVING A CURRENT THAT IS THE SUM OF THE TWO ORIGINAL CURRENTS. The two sources shown above have been combined into a single source supplying $(I_1 + I_2)$ amperes.

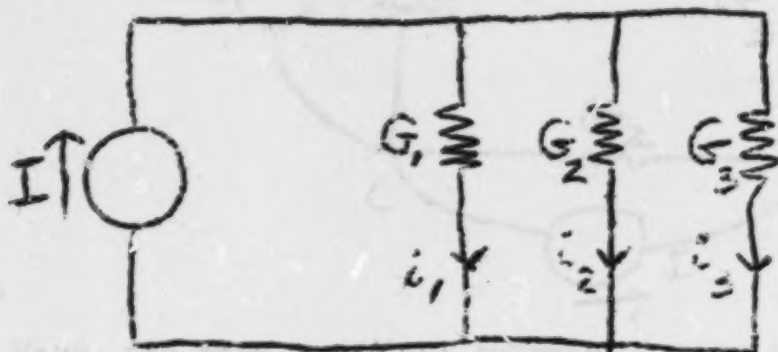
The direction of the arrow on the current source must be noted. In the circuit below, the combined current source is furnishing two amperes of current.



Often it is convenient to think of a "dead" current source -- one whose value has been reduced to zero temporarily. This permits the remainder of the circuit to be analyzed using the principle of superposition. A CURRENT SOURCE WHOSE VALUE IS ZERO IS EQUIVALENT TO AN OPEN CIRCUIT. Another way of thinking about this open circuit is to think of it as an infinite resistance. The circuit on the right below shows an open circuit replacing a dead current source in the circuit on the left.



If we have several resistances connected in parallel with a current source, as shown below, we have a circuit commonly referred to as a "current divider". Here the conductance G is used instead of $1/R$ so the algebra is less cumbersome. The voltage, " v ", is the same across each conductance.



Here, by Kirchhoff's current law

$$I = i_1 + i_2 + i_3$$

and since by the i - v relations

$$i_1 = G_1 v$$

$$i_2 = G_2 v$$

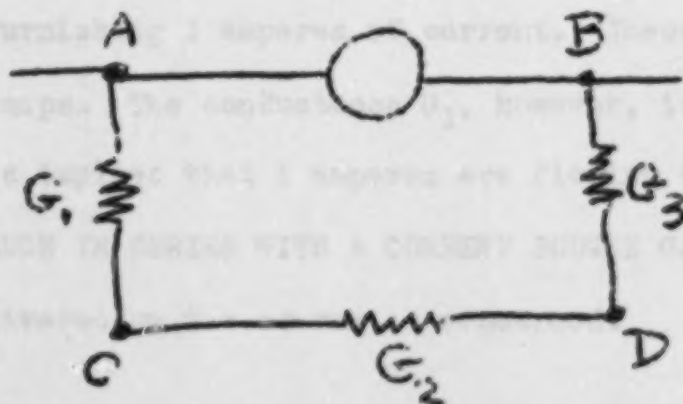
$$i_3 = G_3 v$$

we may also write

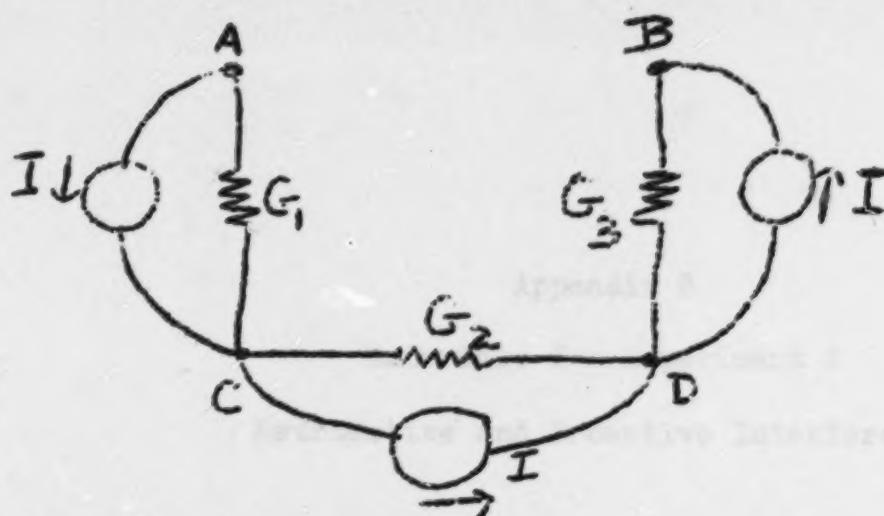
$$I = (G_1 + G_2 + G_3)v$$

Such a circuit is called a "current divider" because the current divides among the possible paths in proportion to the conductances.

Occasionally you will see a partial circuit which does not contain a current source in parallel with a single conductance. Consider the partial circuit shown below:

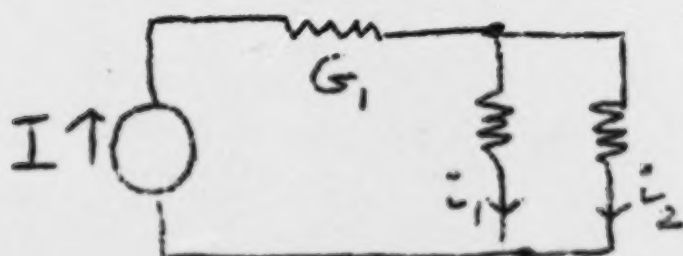


We wish to re-draw this circuit so that the current delivered from node A to node B is I , but we wish the current source I to be in parallel with each of the three conductances. We can transform the circuit as follows:



Here, the same amount of current, namely I , is being pumped from node A to node B, although its route has changed.

A current divider, as we have seen, is obtained by placing two or more conductances in parallel. Consider the current divider circuit in which another conductance has been added that is in series with the current source:



The source is furnishing I amperes of current. These I amperes divide at node A into i_1 and i_2 amps. The conductance G_1 , however, is encountered prior to node A, and this implies that I amperes are flowing through G_1 . This means that a CONDUCTANCE IN SERIES WITH A CURRENT SOURCE CAN BE NEGLECTED as far as the current delivered by the source is concerned.

Booklet on Study Principles

For Experiment I

Appendix B

Materials for Experiment I

Retroactive and Proactive Interference

NAME: _____

Print your name in the space provided. Do not open booklet until instructed

to do so.

**Booklet on Node Principles
for Experiment I**

Educational Experiment No. 3 Node Equations

You have already learned that the relationships existing in planar

circuits can be summarized by writing a **NAME:** node equation, where the number of

unknowns equals the number of equations. It is possible that all these

Print your name in the space provided. Do not open booklet until instructed

to do so.

so that we may solve node equations instead of 2n equations.

The way to do this can best be seen through a specific example. A "ground

node" is first selected. This means merely that we will consider voltages

between the ground node and all other nodes. Thus, the voltage of node "a" is V_a

with respect to ground, and the

voltage of node "b" is V_b with respect to ground.

In the circuit shown at the

left, we will consider first the

current entering node "a". We know

that the sum of all the currents into

any node will always be zero. There-

fore, considering node "a", we have

first that the current source I_1 is

pumping I_1 amount of current into

node "a", and likewise the current I_2 is

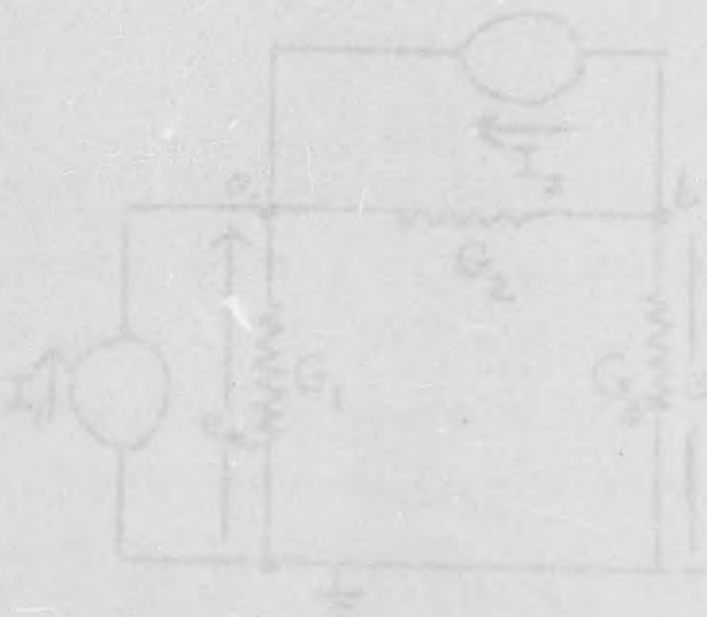
pumping I_2 amount. The total incoming current at node "a" is therefore I_1

plus I_2 .

There are only two paths by which current can leave node "a", one through

the conductance G_1 and the other through the conductance G_2 . So we have

the voltage of node "a" is V_a . Since the voltage across the

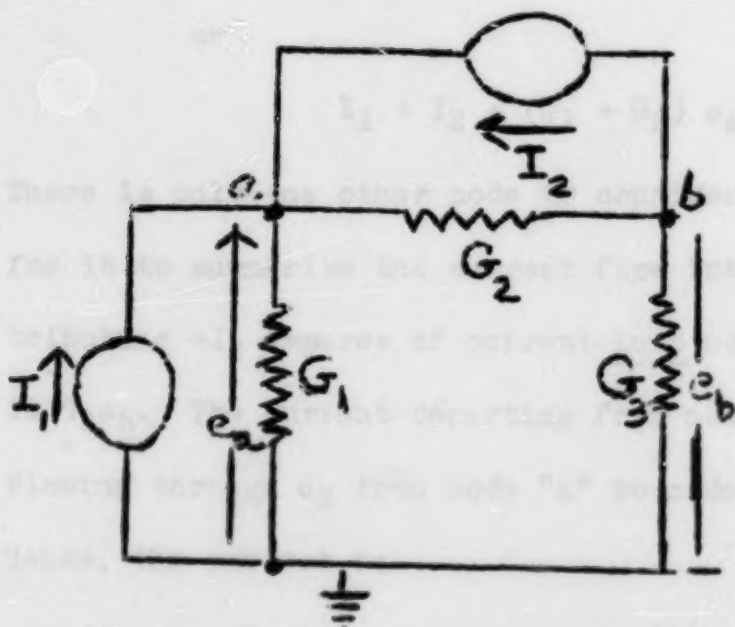


Node Equations

You have already learned that the relationships existing in planar circuits may be summarized by writing a set of $2b$ equations, where the number of unknowns exactly equals the number of equations. It is possible that all these relations may be satisfied, but that the equations may be written in summary form. This smaller set of equations can be written in terms of the $n-1$ node voltages, so that we may solve $n-1$ equations instead of $2b$ equations.

The way to do this can best be seen through a specific example. A "ground node" is first selected. This means merely that we will consider voltages between the ground node and all other nodes. Thus, the voltage of node "a" is e_a

with respect to ground, and the voltage at node "b" is e_b with respect to ground.



In the circuit shown at the left, we will consider first the current coming into node "a". We know that the sum of all the currents into any node will always be zero. Therefore, considering node "a", we have first that the current source I_1 is pumping I_1 amperes of current into node "a", and likewise the source I_2 is

furnishing I_2 amperes. The total incoming current at node "a" is therefore I_1 plus I_2 .

There are only two paths by which current can leave node "a", one through the conductance G_1 and the other through the conductance G_2 . We have already denoted the voltage of node "a" as e_a . Evidently this is a voltage across the

conductance G_1 . Hence, the current flowing away from node "a" through G_1 is then

$$G_1 e_a$$

It only remains to consider the current flowing away from node "a" through G_2 .

The voltage of node "a" with respect to node "b" is $(e_a - e_b)$ -- the total voltage of node "a" with respect to ground minus the voltage of node "b" with respect to ground. The current leaving node "a" through G_2 is then

$$G_2 (e_a - e_b)$$

We have now taken care of all the possible currents converging on node "a", and therefore we can now write an equation summarizing Kirchhoff's current law at this node:

$$I_1 + I_2 - G_1 e_a - G_2 (e_a - e_b) = 0$$

or

$$I_1 + I_2 = (G_1 + G_2) e_a - G_2 e_b$$

There is only one other node to consider, "b", and we wish to write an equation for it to summarize the current flow into that node. The source I_2 is contributing $-I_2$ amperes of current into node "b". The current departing through G_3 is $G_3 e_b$. The current departing from node "b" through G_2 is the negative of that flowing through G_2 from node "a" to node "b", which we have previously found. Hence, the current is

$$-G_2 (e_a - e_b)$$

where $(e_a - e_b)$ is the same voltage drop we used in the first equation. This can be re-written as

$$G_2 (e_b - e_a)$$

We have now taken care of all paths emanating from node "b", so we can write the current equations

$$I_2 + G_2 (e_b - e_a) + G_3 e_b = 0$$

or

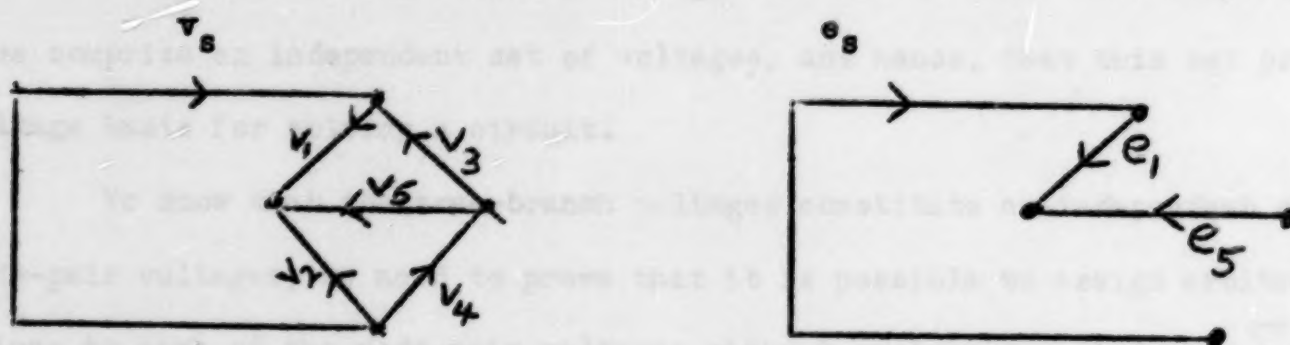
$$-I_2 = -G_2 e_a + (G_2 + G_3) e_b$$

For node "a" we previously wrote

$$I_1 + I_2 = (G_1 + G_2)e_a - G_2e_b$$

Using these last two equations, with numeric values given for G_1 , G_2 , G_3 , I_1 , and I_2 , we can now solve for e_a and e_b the two voltages specifying the relation between nodes and ground.

Even though we know the number of independent voltages that may be used as a basis for solving a circuit using the node-pair method presented above, the choice of which set of $n-1$ voltages to select is not always easy. Some choices will lead to independent sets of simultaneous equations, while other choices will not result in independent equations. For instance, in the figure below on the left, a circuit of six branches is shown. On the right is shown a set of three branch voltages in terms of which all the other voltages may be expressed.



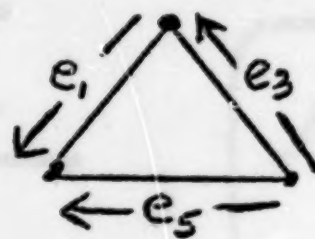
Thus it can be easily seen that v_3 , the voltage associated with branch 3, is $e_5 - e_1$.

A simple method of selecting an independent set of voltages is to construct a tree from the original graph by removing branches in such a way as to insure that all nodes are connected, but there are no closed paths through the resulting graph. A graph in which all nodes are connected and which has no closed paths is called a tree. The branches of the tree are called twigs. For instance, if branches 2, 3, and 4 of the previous graph are removed, we obtain

the graph (A) below, whereas if branches s, 2, and 4 are removed, the graph (B)



(A) Tree corresponding to removal of links 2, 3, and 4 from the previous graph.

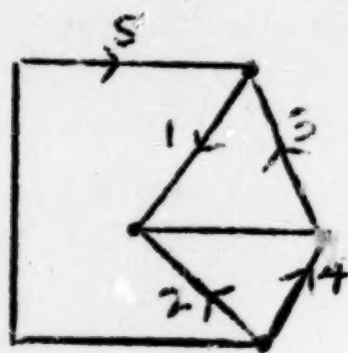


(B) Graph corresponding to removal of branches s, 2, and 4 from the previous graph.

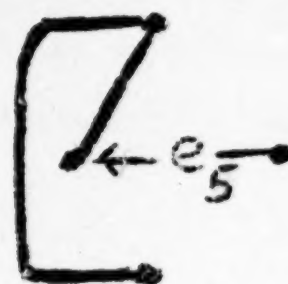
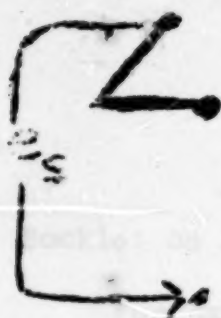
results. The graph (A) above is a tree, whereas graph (B) is not a tree because there remains a closed path or loop.

We shall now show that the voltages associated with each branch of the tree comprise an independent set of voltages, and hence, that this set provides a voltage basis for solving a circuit.

To show that the tree-branch voltages constitute an independent set of node-pair voltages, we need to prove that it is possible to assign arbitrary values to each of the node-pair voltages without violating any of the $\sum v_k = 0$ constraints. Specifically, it should be possible to make all of the tree-branch voltages zero except any one. The easiest way of doing this is to short-circuit all of the node-pairs across which the voltages are to be zero and permit a difference of voltage to arise only across one of the tree branches. When this is done, as in the figure below, it is found that in each case the graph reduces in effect to a single pair of nodes and the tree-voltages may therefore be assigned independently.



Original graph



Each tree-branch, when assigned a non-zero voltage value, separates the tree into two groups of nodes, all nodes of each group having the same voltage.

Here we may express the relationship between the branch and node-pair (i.e. tree-branch) voltages by means of a matrix. With reference to the figures, it is readily seen that for $e_s \neq 0$ and $e_1 = e_5 = 0$, corresponding to the second diagram from the left above, the branch voltages will have the values $e_s = -v_2 = -v_4 = v_5$, and $0 = v_1 = v_3 = v_5$. This fact may be conveniently stated by the first column of the following matrix which shows the contributions made to each branch voltage by the node pair voltage e_s . Likewise, the second column, corresponding to the third graph from the left, shows the voltages across each branch associated with the node-pair voltage e_1 . The last column, corresponding to the right-most graph above, shows the branch voltages associated with the node-pair voltage e_5 .

Node-Pairs - for given tree

	e_s	e_1	e_5
v_5	1		
v_1		1	
v_2	-1	1	
v_3		-1	1
v_4	-1	1	-1
v_5			1

Introductory Systems and Design -- 52.27

Functional Experiment No. 1

Booklet on Loop Principles

for Experiment I

Write your name in the space provided. Do not open booklet until instructed to.

30 ms.

Introductory Systems and Design -- 52.17

Educational Experiment No. 3

LOOP SUPERPOSITION

You have already learned that the relationships existing in circuits may be described by writing a set of K equations. You have learned that the number of unknowns may be evaluated. It is possible to write the equations for the circuit.

NAME: _____

Print your name in the space provided. Do not open booklet until instructed to do so.

currents around each loop in the circuit. All of the K equations must be satisfied but we need to state explicitly only $\frac{1}{2}$ of them. Let us see how this works by examining a specific example. The circuit below contains 2 closed loops -- around each loop a current is flowing in a clockwise direction, and these currents are independent.

The clockwise arrows in the middle of each loop show the direction of the current around each loop. The current around the first loop is i_1 .

The current around the

second loop is i_2 . In one branch

of the circuit, across the branch

containing R_2 , there is a current with value i_1 , contributed by the left loop

and i_2 contributed by the right loop. The total current flowing through R_2 in

the downward direction is therefore $i_1 + i_2$. Using Kirchhoff's voltage law we

can write two equations in terms of the loop currents because we know that the

voltages around any loop must sum to zero. For the left loop we can write

$$\begin{array}{lll} \sum & = & \\ \text{(Total applied)} & \text{(Voltage} & \text{(Voltage drop} \\ \text{voltage)} & \text{drop across} & \text{across } R_2) \\ & R_1 & \end{array}$$



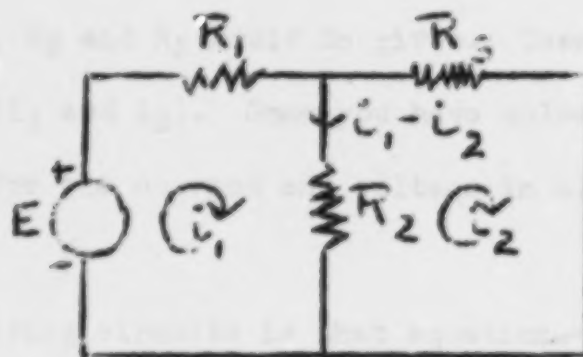
Int. Systems and Design - 52.17

Educational Experiment #3

LOOP EQUATIONS

You have already learned that the relationships existing in circuits may be summarized by writing a set of $2b$ equations. You have learned that the number of unknowns may be evaluated. It is possible to reduce drastically the amount of labor in solving a circuit by writing a set of equations in terms of the circulating currents around each loop in the circuit. All of the $2b$ equations must be satisfied but we need to state explicitly only ℓ of them. Let us see how this works by examining a specific example. The circuit below contains 2 closed loops -- around each loop a current is flowing in a clockwise direction, and these currents are independent:

The clockwise arrows in the middle of each loop show the direction of the current around each loop. The current around the first loop is i_1 . The current around the second loop is i_2 . In one branch of the circuit, namely, the branch



containing R_2 , there is a current with value $+i_1$, contributed by the left loop and $-i_2$ contributed by the right loop. The total current flowing through R_2 in the downward direction is therefore $i_1 - i_2$. Using Kirchhoff's voltage law we can write two equations in terms of the loop currents because we know that the voltages around any loop must sum to zero. For the left loop we can write

$$\begin{array}{rcl}
 E & = & R_1 i_1 + R_2(i_1 - i_2) \\
 \text{(Total applied voltage)} & & \text{(Voltage drop across } R_1) \quad \text{(Voltage drop across } R_2)
 \end{array}$$

There is no applied voltage source in the right loop so the equation for this loop, obtained in exactly the same manner as the equation above is

$$0 = R_3 i_2 - R_2(i_1 - i_2)$$

The only possible difficulty here is that the last term, $-R_2(i_1 - i_2)$, has a negative sign. If you glance back at the diagram, you will see that i_1 and i_2 have both been defined in a clockwise direction and clockwise voltage drops are therefore taken to be positive. The current $i_1 - i_2$, is flowing in a counter-clockwise direction, and therefore it causes a negative voltage drop in the clockwise direction.

It is convenient to re-write these two equations:

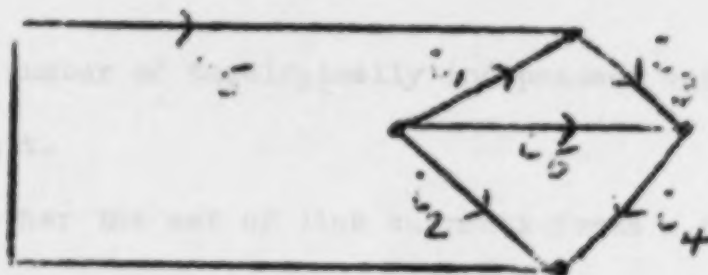
$$E = (R_1 + R_2) i_1 - R_2 i_2$$

$$0 = -R_2 i_1 + (R_2 + R_3) i_2$$

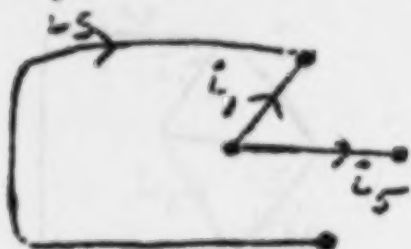
In a numerical problem, values for E , R_1 , R_2 and R_3 would be given. Then you will have two equations in two unknowns (i_1 and i_2). Once you have solved for these two currents, it is easy to solve for the current and voltage in all of the $2b$ branches in the circuit.

The whole strategy of this method for solving circuits is that equations are written in terms of currents, and Kirchhoff's current law is satisfied at every node. We have condensed the information contained in $2b$ equations (6 equations for the 2 loop circuit) into ℓ equations (2 equations for the 2 loop circuit).

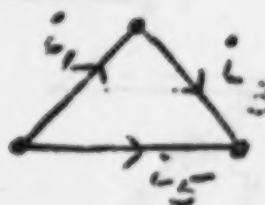
Even though we know the number of independent currents that may be used as a basis for solving the circuit, the choice as to which set of ℓ currents to select is not always apparent. A variety of choices is possible. Some sets of currents will be independent, while others will not be independent. For instance, in the graph below, i_2 , i_3 and i_4 constitute an independent set (i.e. a basis), whereas i_1 , i_2 and i_4 are dependent.



A simple method for selecting an independent set of branch currents is to construct a tree from the original graph by removing branches in such a way as to insure that all nodes are connected but there are no closed paths through the resulting graph. A graph in which all nodes are connected and which has no closed paths is called a tree. The branches of the tree are called twigs. For instance, if branches 2, 3, and 4 of the previous graph are removed, we obtain the graph (A) below, whereas, if branches 1, 2, and 4 are removed, graph (B) results.



(A) Tree with branches 2, 3, and 4 removed.



(B) Graph corresponding to removal of branches 1, 2, and 4.

Graph (A) is a tree, whereas Graph (B) is not a tree.

We shall now show that the currents associated with each of the links (i.e. branches removed in forming a tree) comprise an independent set of currents and hence, provide a current basis.

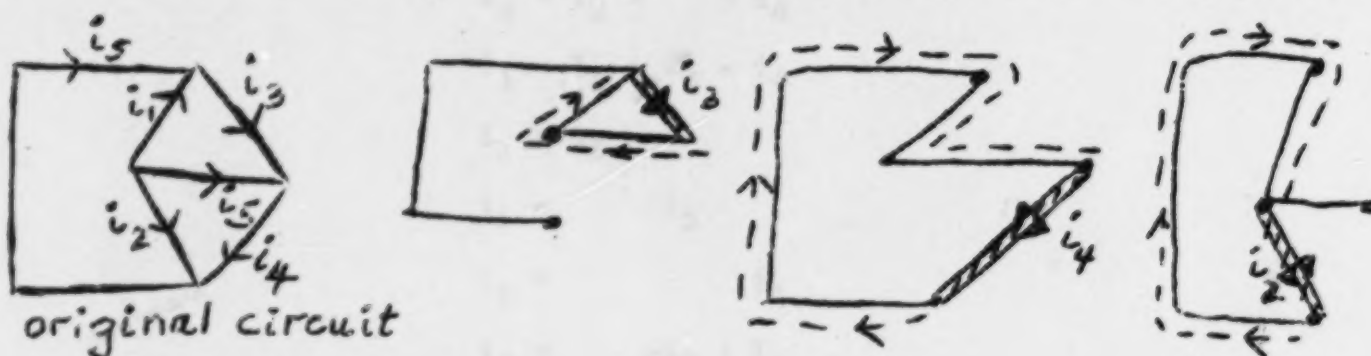
First of all, how many links are there? If the total number of nodes in the tree is n_t , then it is easy to see that the number of branches in the tree (only) must be $(n_t - 1)$, for upon adding the first branch, two nodes are connected and each additional branch connects one additional node into the tree. Hence, the number of tree branches is one less than the number of nodes.

But the original graph contained b branches. Hence, the number of link branches that must be removed in forming a tree is,

$$l = b - (n_t - 1)$$

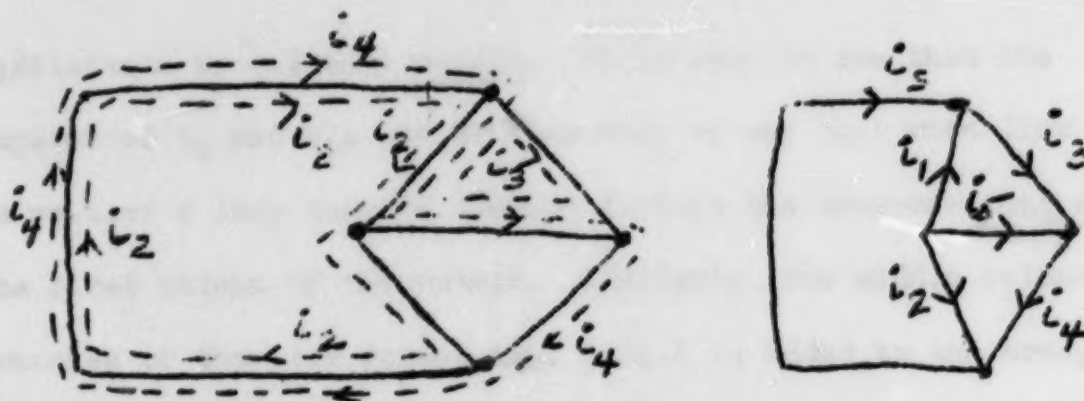
which is precisely the number of topologically independent currents associated with the original circuit.

Next we need to ask whether the set of link currents forms a topologically independent set. If so, it should be possible to assign arbitrary values to each of the link currents without violating any of the $i_k = 0$ constraints. Specifically, it should be possible to make all of the link currents zero, except any one. The easiest way to do this is to omit the links in which the currents are to be zero, and then to replace the one link in which current is to flow. When this is done as in the figure below, in each case there is a single closed path through the circuit -- so the link currents are indeed independent.



Each link, when it alone is added to a tree, forms a uniquely defined closed path around which the link current flows.

Each link current, in flowing through the tree, describes a closed loop through the circuit. The number of these independent loops or closed paths through the circuit is precisely $\mathcal{L} = b - (n_t - 1)$. When the entire set of independent currents i_2, i_3 , and i_4 flow through the circuit, the contribution of each to the current in any branch may be visualized easily by superimposing the streamlines of the figure above.



Using the principle of superposition the b branch currents may be expressed in terms of the l loop currents.

Notice that the current in any branch may be expressed in terms of these three loop currents:

$$i_s = i_2 + \quad + i_4$$

$$i_1 = -i_2 + i_3 - i_4$$

$$i_2 = i_2$$

$$i_3 = \quad i_3$$

$$i_4 = \quad i_4$$

$$i_5 = \quad -i_3 + i_4$$

We will often encounter sets of algebraic equations such as these and it will be convenient to write these equations in tabular form, showing only the coefficients appearing in the equations. Thus, we can write each current once and for all at the head of the column in which the coefficients associated with that current are written; (if nothing is written, the value of the coefficient is taken to be zero).

	Loops		
	i_2	i_3	i_4
i_s	1		1
i_1	-1	1	-1
i_2	1		
i_3		1	
i_4			1
i_5		-1	1

Branches

This table of coefficients is called a matrix. It is easy to see that the current i_g is composed of i_2 and i_4 . It is also easy to see that when link 2 is added to the tree we have a loop current flowing through the branches that are represented in the first column of the matrix. Similarly, the middle column represents the branches of the loop formed when link 3 is added to the tree, and the last column represented the branches of the loop associated with link 4.

INTRODUCTION

Problems in many fields can be formulated in terms of sets of quantities which are linearly related to one another. To deal methodically with large numbers of such quantities, we need a compact notation. This need is met by matrix notation. This notation allows calculations and permits operations to be performed without cluttering up the work with a lot of numerical details. This notation is particularly well adapted for the computer solution of problems where we wish to concentrate upon the overall logic of problem solution rather than upon numerical details.

Booklet on Matrix Theory

(Neutral Material)

For Experiment I

Any circuits containing only resistance (or conductance) elements in various combinations may be solved by setting up sets of simultaneous algebraic equations. To write the equations for a circuit containing 50 branches is no more difficult in principle than to write a set for a circuit with 2 branches. An efficient method for solving these sets of equations is at hand when the coefficients in the equations are expressed in matrix notation, because a digital computer is well-adapted to handling matrices.

A matrix is a rectangular array of numbers, such as that shown below, and may be denoted by a single symbol, such as A .

	1	2	3
1	1	-4	6
2	5	3	0
3	1	8	2
4	4	7	8

In the above example, the wiggly line underneath the symbol is typewritten text indicating the equivalent of a bold face symbol, is printed text. The matrix may be denoted by a single symbol or by two rows. It is often convenient to place an index alongside each row, and also an index at the head of each

MATRICES

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A matrix is a rectangular array of numbers, such as that shown below, and may be denoted by a single symbol, such as A

$$\underset{\sim}{A} = \begin{array}{c|ccc} & 1 & 2 & 3 \\ \hline 1 & 1 & 4 & 6 \\ 2 & 3 & 2 & 0 \\ 3 & 1 & 5 & 2 \\ 4 & 4 & 7 & 8 \end{array}$$

In the above example, the wiggly line underneath the symbol in typewritten text indicates the equivalent of a bold face symbol in printed text.

The matrix may be decomposed into columns or into rows. It is often convenient to place an index alongside each row, and also an index at the head of each

column. In the example shown above, the 4 rows are designated respectively by the indices 1, 2, 3, and 4 respectively, whereas the three columns are designated by the indices 1, 2, and 3. It is conventional to describe any element in the matrix by giving first the index of its row and then the index of its column. By extension of this idea, A_{12} is the element in the first row and second column of the matrix A . Numerically, $A_{12} = 4$ in the example shown. More generally, the element in the i 'th row and j 'th column is designated by the symbol A_{ij} .

Sometimes we may wish to select a particular row, or a particular column of a matrix. Here we may follow Bodewig* and use a dot to denote an index that is to range over all of its values, so that the second row of the matrix A would be indicated as $A_{2.}$, whereas the second column would be indicated by $A_{.2}$. Alternatively, we may sometimes use the two pointed brackets, $\langle$ or $\rangle$, to emphasize that a single row or column respectively is indicated. Thus

$$A_{2.} = \langle A_{2.} = \begin{array}{c|c|c} 1 & 2 & 3 \\ \hline 3 & 2 & 0 \end{array}$$

whereas

$$A_{.2} = A_{.2} \rangle = \begin{array}{c} 2 \\ \hline 4 \\ \hline 2 \\ \hline 5 \\ \hline 7 \end{array}$$

Likewise,

$$\begin{aligned} A_{13} &= 1 \begin{array}{c} 3 \\ \hline 6 \end{array} \\ A_{42} &= 4 \begin{array}{c} 2 \\ \hline 7 \end{array} \end{aligned}$$

which selects an element in a particular row and a particular column. In contrast, $A_{..}$ represents the entire collection of rows and columns and is equivalent to the matrix A itself. A is also written as $\|A_{ij}\|$.

*Bodewig, E., Matrix Calculus, Interscience Publishers, Inc., New York.

By using a single letter, such as $\underline{A}$ to denote a table of numbers, we may refer to the entire table without listing the detailed numbers which comprise it. Furthermore, a subscript may be used to select out of the table a single row (or a single column), and two subscripts may be used to select any single element in the table. Thus, a matrix provides a convenient arrangement for organizing sets of numbers.

We next shall define various rules for manipulating and combining matrices and numbers so that we can treat these matrices very much as though they were ordinary algebraic quantities. For instance, the voltage equations of a circuit of arbitrary complexity may be written in matrix form as $\underline{E} = \underline{R} \underline{I}$. Assuming that the elements in the $\underline{E}$ column are known, as are also the elements in the $\underline{R}$ matrix, the solution for the unknown currents, which form the $\underline{I}$ column, may be written as $\underline{I} = \underline{R}^{-1} \underline{E}$. The solution requires that we determine a new matrix $\underline{R}^{-1}$, which is called the inverse of $\underline{R}$. This matrix is defined in such a way that when the above expression is evaluated according to the rules, the correct answer will be obtained. In fact, calculating the matrix $\underline{R}^{-1}$ from a given matrix $\underline{R}$ is a task that almost any digital computer today "knows how to do" without further instruction. Even so, you should acquire sufficient familiarity with matrix algebra to have some insight into why it works and how it is applied to various problems. Accordingly, the following sections summarize briefly the essential aspects of matrix algebra needed in our work.

In order for two matrices to be equal, their corresponding elements must be equal. This implies that the two matrices must have the same number of rows and the same number of columns. That is,

$$\text{Equality: } \underline{A} = \underline{B} \text{ implies that } A_{jk} = B_{jk} \quad (10)$$

for all j and k .

The sum of two compatible matrices is obtained by adding the corresponding elements, viz.

Summation: $C = A + B$ implies $C_{jk} = A_{jk} + B_{jk}$ (11)

A matrix may be multiplied by an ordinary number (i.e. a scalar) by multiplying each element of the matrix by that number. Thus, if c is any scalar,

Scalar Multiplication: $B = cA$ implies $B_{jk} = cA_{jk}$ (12)

This rule is consistent with the summation rule and permits us to write such expressions as $A + A = 2A$.

We must also define the product of two matrices. Let A be a $\ell \times m$ matrix and B be a $m \times n$ matrix. Then the product $C = AB$ is a $\ell \times n$ matrix whose elements are given by

$$C_{jk} = \sum_{i=1}^m A_{ji} B_{ik} \quad (13)$$

The meaning of this expression is clarified by the following example:

$\swarrow j \quad i$	1	2	3	4	1	2	3	1	2	3		
1	1	2	3	0	1	1	4	6	1	14	18	9
2	3	2	1	0	2	2	1	0	2	10	18	19
					3	3	4	1				
					4	2	0	5				
<u>A</u>	.				<u>B</u>	=			<u>C</u>			

Here, A is a (2×4) matrix, B is a (4×3) matrix, and the product C is a (2×3) matrix. To find the value of C_{jk} according to equation (13), we select the j 'th row of the A matrix and the k 'th column of the B matrix, multiply elements corresponding to the same value of the index i , and sum these products. For instance, to find $C_{1,1}$ we select row A_1 and column B_1

$\swarrow j \quad i$	1	2	3	4	1	2	3
1	1	2	3	0	1	1	
					2	2	
					3	3	
					4	2	
							= 1 + 4 + 9 + 0 = <u>14</u>

Likewise, to find $C_{2,3}$ we form the product of $A_{2,}$ and $B_{,3}$, viz.

$$\begin{array}{c}
 \begin{array}{ccccc}
 & \xrightarrow{\quad} & & & \\
 1 & 1 & 2 & 3 & 4 \\
 \hline
 2 & 3 & 2 & 1 & 0
 \end{array}
 \quad
 \begin{array}{c}
 \downarrow \\
 \begin{array}{c}
 1 \swarrow \\
 \begin{array}{c}
 1 \\ 2 \\ 3 \\ 4
 \end{array}
 \end{array}
 \begin{array}{c}
 6 \\ 0 \\ 1 \\ 5
 \end{array}
 \end{array}
 = 18 + 0 + 1 + 0 = \underline{\underline{19}}
 \end{array}$$

Continuing in this manner, verify that the elements of the C matrix have the following values.

$$\begin{array}{c}
 \underline{\underline{C}} =
 \end{array}
 \begin{array}{c}
 \begin{array}{c}
 \swarrow \\
 \begin{array}{c}
 1 \\ 2
 \end{array}
 \end{array}
 \begin{array}{c}
 \begin{array}{ccc}
 1 & 2 & 3 \\
 \hline
 1 & 14 & 18 & 9 \\
 2 & 10 & 18 & 19
 \end{array}
 \end{array}
 \end{array}$$

Posttest for Experiment II

Educational Experiment No. 3

NAME _____

Please print your name on the line above. Do not open booklet until instructed to do so.

As you work through this booklet, please do not turn back to any previous section.

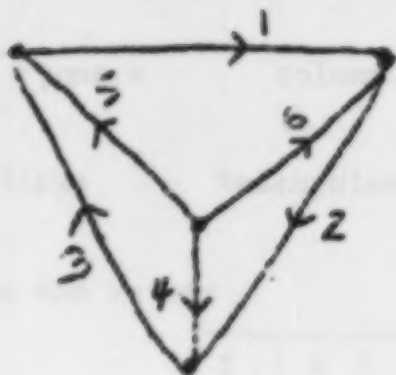
Some of the questions below require that you supply a word or an equation.

Select words or equations from the following list:

capacitance(s)	row	current(s)	twigs
diagonal	$\sum v_k = 0$	branches	inductance(s)
conductance(s)	loop	square	column
resistance(s)	node	links	triangular
rectangular	$v = Ri$		voltages

1. The fundamental principle used in writing loop equations is _____.
2. A current basis (set of independent currents) is obtained from the _____ of a tree.
3. In writing node equations the numeric coefficients are most easily expressed as _____.
4. The elements in a matrix used to solve a set of node equations are _____ values.
5. In writing a set of loop equations the basis quantities are _____.
6. After solving a set of node equations, the _____ may be found by using $i = gV$ relations.
7. A matrix is a _____ array of n rows and n columns.

8. In the circuit shown below having the six branches 1, 2, 3, 4, 5, 6, check those sets of branches listed which form a tree:



Branches

Check, if a tree

1, 2, 3, 4

☐

1, 2, 3

☐

1, 2, 4

☐

5, 6, 4

☐

9. A circuit is arranged in the form of the edges of a cube (see below). How many links must be removed to form a tree?



ANS _____

10. Check the box alongside the correct answer for the multiplication of the two matrices shown below.

3	-1
-1	4

2	3
1	2

=

5	2
7	5

☐

5	-2
0	6

☐

5	7
2	5

☐

Capactance(s) row(s) current(s) twigs diagonal

$\sum v_k = 0$ branches inductance(s) conductance(s)

loop square column(s) $\sum i_k = 0$ resistance(s)

node links triangular voltages rectangular $v = ri$

11. Given the matrix

$\underline{A} =$

1	4	6
3	2	0
1	5	2
4	7	8

the value of the element

A_{32} is _____

The value of the element

A_{23} is _____

12. The fundamental principle used in writing node equations is _____.

13. A voltage basis (set of independent voltages) is obtained from the
_____ of a tree.

14. In writing loop equations, the numeric coefficients are most easily
expressed as _____.

15. In writing a set of node equations the basis quantities are _____.

16. After solving a set of loop equations, the _____ may be found
by using $v = ri$ relations.

17. The elements in a matrix used to solve a set of loop equations are
_____ values.

18. In multiplying two matrices A and B, the product will be a matrix having
the same number of _____ as matrix A.

INTRODUCTORY SYSTEMS AND DESIGN 52-17

EDUCATIONAL ELEMENT 94

Name _____

Please print your name in the space above.

DO NOT OPEN THIS BOOKLET UNTIL TOLD TO DO SO.

**Programmed Booklet on Flowgraphs
for Experiment II**

INTRODUCTORY SYSTEMS AND DESIGN 52.17

EDUCATIONAL EXPERIMENT #4

Name: _____

Please print your name in the space above.

DO NOT OPEN THIS BOOKLET UNTIL TOLD TO DO SO.

Turn the page and start reading. If you have any questions, raise your

hand, and we will answer your questions on an individual basis.

The pages which follow contain one paragraph each. After reading the paragraph, you will see a sentence at the end with a blank left in it. Try to fill in the blank. You should have no difficulty filling in the blank after you have read the paragraph. After you have filled in the blank, turn the page, and there you will see what should have been put in the blank. These blank spaces are left so that you may check yourself as you go along, and be sure you understand what you are reading. This is not a test -- the blanks are left so that you will be able to learn the material more easily.

Turn the page and start reading. If you have any questions, raise your hand, and we will answer your questions on an individual basis.

The symbols of circuit theory -- those symbols used in drawing circuit diagrams -- may be thought of as a kind of mathematical notation. They specify in a compact way the relationships between the signals (voltages and currents). After voltages and currents have been determined, the circuit diagram expresses very concisely the relationships that the currents and voltages must satisfy. A circuit diagram is equivalent to a set of algebraic equations relating the signals.

A circuit diagram portrays the relationships among the various currents and voltages in a circuit.

By writing, and the solution is almost immediate for any variable desired.

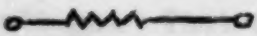
Flowgraphs provide a graphical means for solving circuits.

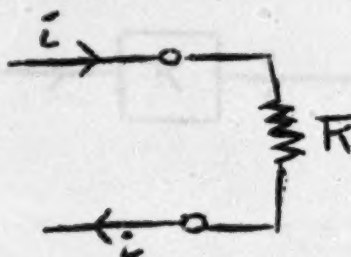
ANS. relationships

Circuit diagrams are very useful and almost indispensable in solving linear circuits. They permit the writing of sets of equations that display symmetry and other nice properties when certain conventions are followed. On the other hand, solution of circuits this way is a two-pass method. The circuit diagram must first be drawn, and then sets of equations must be written and solved. If you wish to know the values for only one or two signals, the entire set of equations may need to be solved. With flowgraphs a "graph" can be written, and the solution is almost immediate for any variable desired.

Flowgraphs provide a _____ pass method for solving circuits.

ANS. one

The linear, stationary circuit elements that we have thus far introduced are the resistance, the inductance, and the capacitance. The symbol, , may represent a physical thing called a resistor which has a value of R ohms, or it may represent a particular relationship between a current and voltage such that



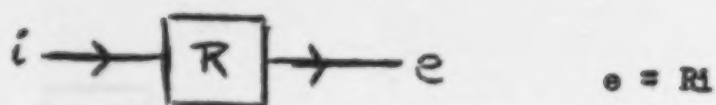
$$e = R \cdot i$$

It is this second meaning that has relevance to the construction of circuit theory. Thus, a resistance symbol stands for a particular relationship between a current and a voltage.

For circuit theory, resistors (or inductance or capacitance elements) depict the relation between a particular current and _____.

ANS. voltage

Expressing this idea in yet another way, we may think of the resistance symbol as representing some kind of process that transforms a current into a voltage. That is, we can regard the current as the input (or cause) and the voltage as the output (or response) of some operator, viz.

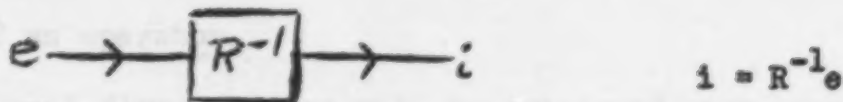


The "block-diagram" symbol just used differs from the resistance symbol in that the block stands for nothing more than that relation which yields the value of e when i is given.

In a block diagram with current as input and voltage as output, the resistance symbol represents a process which _____ the current into voltage.

ANS. transforms

Another important distinction will be noted between these two symbolic notations for the relationship, $e = Ri$. The resistance symbol does not imply a cause-and-effect relationship, whereas the block-diagram definitely does. Thus, the same resistance symbol might equally well be used to denote the expression $i = R^{-1}e$, whereas the block (or "operator") diagram would now read



The "box" may be interpreted as denoting whatever it is that "operates" upon the voltage e to yield the current i. Here, e is identified as the cause and i as the effect.

A block-diagram implies a _____ relationship.

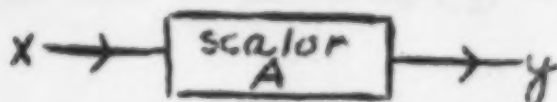
ANS. causal or cause-and-effect

The foregoing discussion suggests that just as we have developed a theory and notation for circuit elements (such as resistors, inductors, capacitors and the like) which will be useful in assembling these things into the proper configurations, so likewise we should find it helpful to develop a theory and a notation for expressing clearly the properties of the signals that are associated with the circuit. For this purpose, we shall focus attention upon the notion of an operator.

In signal flowgraphs we will be concerned with signals and their transformation by _____.

ANS. operators

Perhaps the simplest operator is the scaler. When a scaler operates upon any signal x, it will yield another signal y whose value is some constant A times the value of x. This relationship may be denoted symbolically by



$$\text{where } y = Ax$$

A scaler may be described completely by specifying the value of the constant A. This constant may be determined by dividing the value of the output signal y by the corresponding value of the input signal x. A is called the transmittance of the operator. The transmittance of any scaler is:

$$\text{transmittance} = \frac{\text{output-signal value}}{\text{input-signal value}}$$

The scaler is one type of _____; its transmittance is the output signal value divided by the input signal value.

ANS. operator

Now, let us describe a linear resistor by its effect upon the current and voltage signals associated with it. If we regard the current, i , as the cause and the voltage, e , as the effect, then, clearly, whatever the value of the current i , the value of the voltage, e , will be R times that of the current, and hence,

$$\text{transmittance} = \frac{R \cdot i}{i} = R .$$

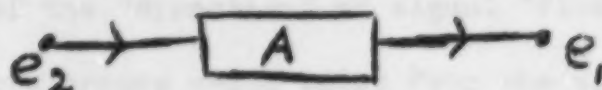
Likewise, if we regard the voltage as the cause and the current as the effect, the same device may be described by an operator whose transmittance is

$$\text{transmittance} = \frac{G \cdot e}{e} = G .$$

We are now thinking of currents and voltages as _____ and will study the relations between these _____.

ANS. signals signals

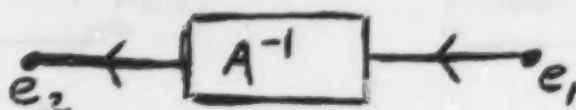
In operator notation e_2 (see diagram) is regarded as an "input" signal.



A is the scalar which transforms the input signal e_2 into e_1 , where e_1 is the "output" signal. If $A = 2$ then

$$e_1 = 2e_2$$

Suppose now we want to make a block diagram with e_1 as input and e_2 as output but maintain the same relation between e_1 and e_2 as before. We write



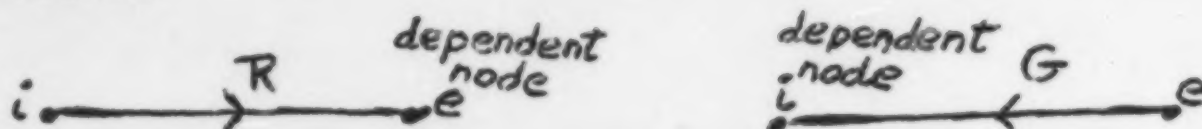
and clearly A^{-1} must equal $1/2$.

If we think of e_2 as depending on e_1 , we must indicate the direction of the dependency by arrows and the transmittance is the _____ of the former transmittance.

ANS. reciprocal

This example shows why it is important to associate with each transmittance some indicator of the "direction" of signal "flow". This is usually indicated by one or more arrows which point from the assumed "cause" to the assumed "effect".

Now, a signal-flow graph utilizes a still more streamlined symbolism than the block diagram. Only two symbolic elements are employed: a node to represent a signal, and a directed branch to represent the dependency of one signal on another. Thus, the flow-graphs for the signals associated with a resistor are



depending on whether "i" or "e" is considered the "cause". The arrow shows which variable is _____.

ANS. dependent

Although we have talked so far mostly about currents and voltages as signals, this is by no means necessary. A signal can be any observable, such as charge, velocity, force, acceleration, temperature, pressure, etc., to name a few of the signals encountered in physical problems. For this reason flowgraphs may be used to solve many kinds of linear systems, and are thus more generally useful than circuit diagrams.

In flowgraphs a signal may represent any _____.

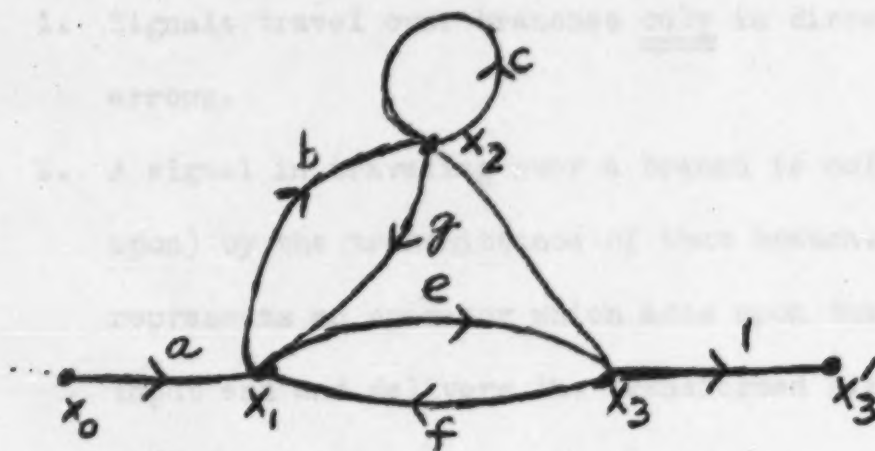
To interpret this graph, we must agree on the rules that govern these symbols and their manipulation.

We have already stated that each node represents a signal. For instance, the node signal, x_i , is the value of the signal represented by node i . The directed branch, U_{ij} , may be thought of as outgoing from node i and incoming at node j . The branch U_{ij} may be thought of as having its input at node i and its output at node j .

The branch U_{31} has its input at node _____ and its output at node _____.

ANS. observable

A more complicated flow-graph is shown below:



To interpret this graph, we must agree on the rules that govern these symbols and their manipulation.

We have already stated that each node represents a signal. For instance, the node signal, x_1 , is the value of the signal represented by node 1. The directed branch, 01, may be thought of as outgoing from node 0 and incoming at node 1. The branch 01 may be thought of as having its input at node 0 and its output at node 1.

The branch 33' has its input at node _____ and its output at node _____.

ANS. 3 3'

Two of the rules governing flowgraphs are:

1. Signals travel over branches only in directions indicated by the arrows.
2. A signal in traveling over a branch is multiplied (or operated upon) by the transmittance of that branch. Thus, each branch represents an operator which acts upon the node signal at its input end and delivers the transformed signal to its output node.

A signal traveling over a directed branch in a flowgraph is _____, by the transmittance of that branch.

When a node has more than one incoming branch, the signal at the node is the _____ of the signals coming in.

ANS. multiplied or operated upon

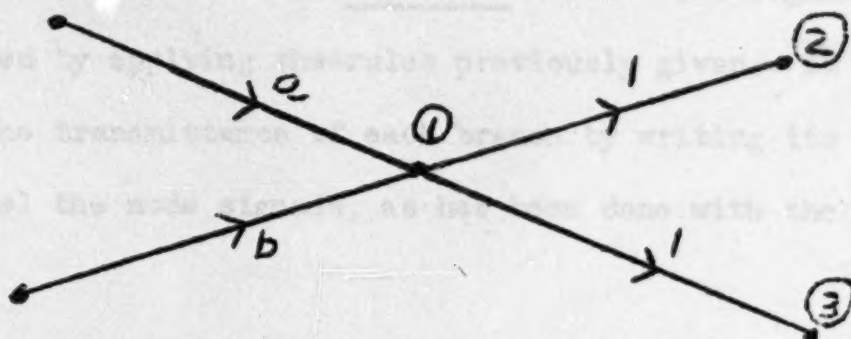
We also need some rules to specify what happens when more than one branch terminates on a node. A node with one or more incoming branches is a dependent node.

1. The signal represented by any dependent node is the algebraic sum of all signal flow into that node. (Observe that the value of a node signal is in no way related to the number of branches which leave the node; only the signal flow into the node determines its value.)
2. The signal at any node serves as the input for all branches leaving that node.

When a node has more than one incoming branch, the signal at the node is the _____ of the signals coming in.

ANS. sum

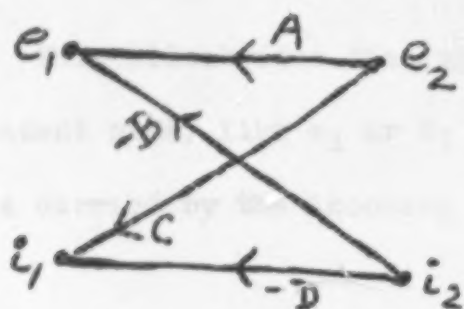
Let us review what was stated on the preceding page. In the graph below signals travel over branches a and b to node "1".



At node "1" the signals add together and their sum is transmitted out to both nodes "2" and "3". If the signal out of branch a has the value 5 and the signal out of branch b has the value 3, the value of the signal at node "2" is equal to 8 and the value of the signal at node 3 is also equal to _____.

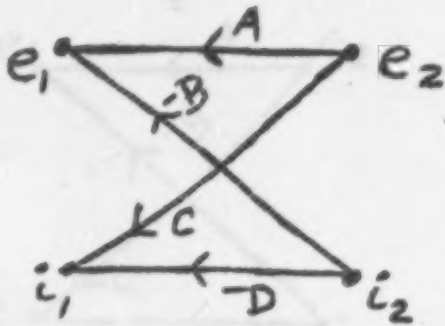
ANS. 8

A source node has no incoming branches. It is used to represent a signal of known or specified value. All other nodes, having one or more incoming branches, are called dependent nodes. The signal at any dependent node is determined by applying the rules previously given. It is customary to designate the transmittance of each branch by writing its value alongside, and also to label the node signals, as has been done with the flowgraph immediately below.



In accord with the definitions just given, the source nodes of the graph at the left are e_2 and i_2 .

A source node has _____ incoming branches.

ANS. no

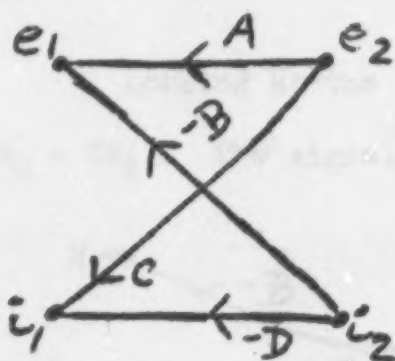
For the graph shown, the total signal flow into the dependent nodes e_1 and i_1 may be

written as

$$e_1 = Ae_2 - Bi_2$$

$$i_1 = Ce_2 - Di_2$$

This illustrates the important principle that the value of a signal at a dependent node, like e_1 or i_1 above, is the _____ of the signals carried by the incoming branches.

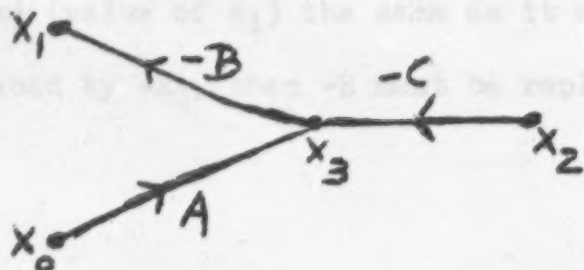
ANS. sum

This same graph also points up the fact that the signal value at a source node (e_2 or i_2) is multiplied by the transmittance of the

branch the signal traverses. Thus, when the signal e_2 traverses the branch whose transmittance is A it is multiplied by _____.

ANS. A

Looking at the graph on the left below, we see that the signal at x_3 is $Ax_0 - Cx_2$. The signal at x_1 is $-Bx_3$. The signal at x_1 may also be written



as $-B(Ax_0 - Cx_2)$ if we substitute the previously determined value for the signal at x_3 .

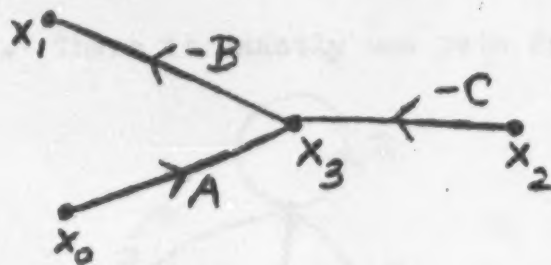
If another outgoing branch were added to node x_3 with a transmittance of 1, its output signal would be _____.

ANS. x_3 or $Ax_0 - Cx_2$

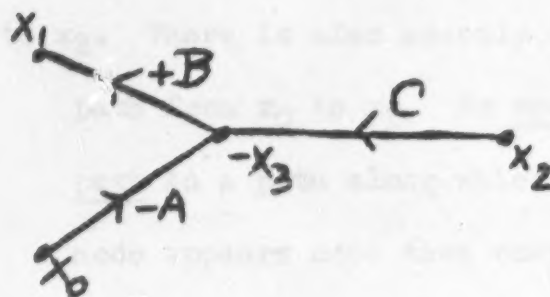
Suppose we draw another graph, which is exactly like the last except that x_3 is now written with a minus sign preceding. We wish to keep the output signal (value of x_1) the same as it was before. Its value was $-Bx_3$. If x_3 is replaced by $-x_3$, then $-B$ must be replaced by _____.

ANS. +B

But moving back another step, x_3 was also equivalent to $Ax_0 - Cx_2$. So if x_3 is replaced by $-x_3$, we must write $-Ax_0 + Cx_2$. so now the graphs are



original graph

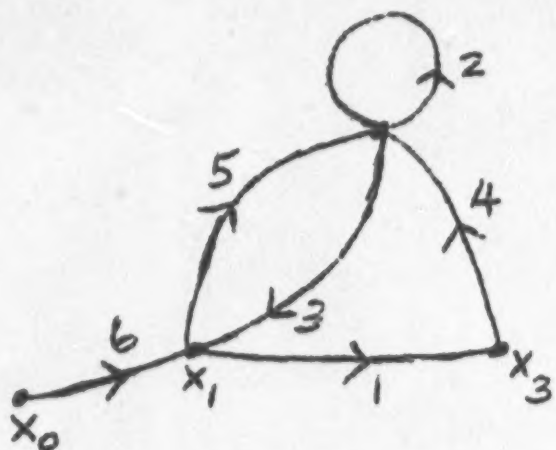


If we wish to maintain the correct signals at all other nodes of the original graph when the sign of the signal at one of the nodes is changed, we must change the signs of all branches that _____ the node whose signal sign was changed.

ANS. touch

You will need to understand loops clearly in order to work with flow-graphs. To define loops precisely, we must first define a path.

A path is a succession of branches traversed in the direction shown by arrows. There is exactly one path from x_3 to x_2 . There is also exactly one

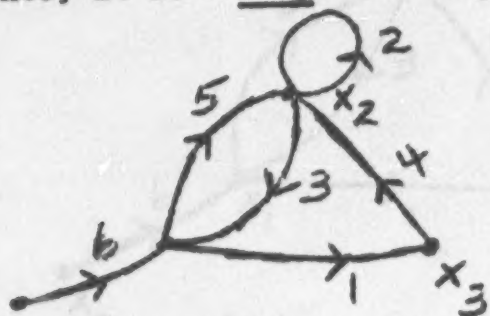


path from x_0 to x_1 . An open path is a path along which no node appears more than once.

Both the path from x_3 to x_2 and the path from x_0 to x_1 are open paths. Is there a path from x_1 to x_0 ?

ANS. No

If a path begins and ends on the same node but traverses no node more than once, it is a loop. The topmost part of the graph beginning and ending



on node x_2 is a loop (sometimes called a self-loop since it consists of one branch that begins and ends on the same node.)

Can a loop include more than one branch?

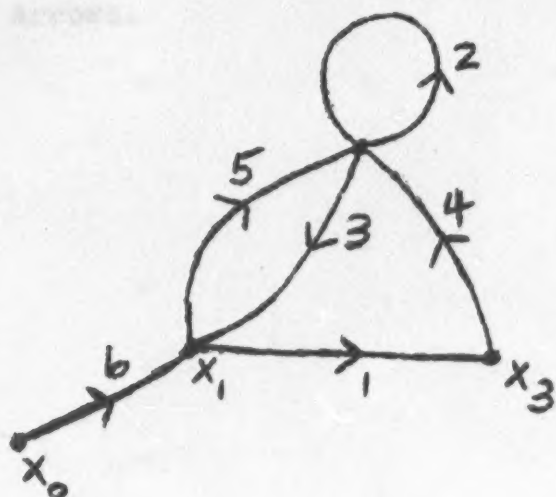
Clearly also, there are other loops in this graph. The part of the graph shown below is a loop — we can start at node x_1 (or x_2 or x_3) and follow



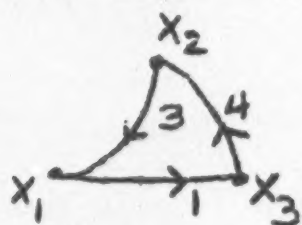
a path indicated by tapered arrows and arrive back at x_1 .

Is the part of the graph shown below a loop?



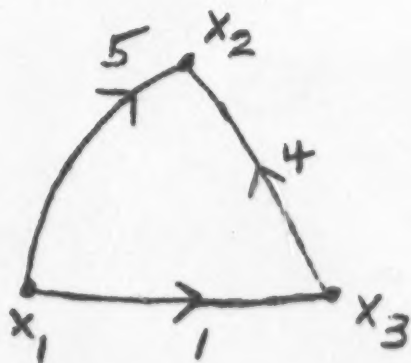
ANS. Yes

Clearly also, there are other loops in this graph. The part of the graph shown below is a loop -- we can start at node x_1 (or x_2 or x_3) and follow



a path indicated by branch arrows and arrive back at x_1 .

Is the part of the graph shown below a loop?



ANS. No - Cannot travel from x_2 to x_3 because signals cannot travel against arrows.

Preview Material for Experiment II

Read by Experimental Group

SIGNAL DIAGRAMS ARE DIFFERENT FROM ELEMENT DIAGRAMS IN THAT
SIGNAL DIAGRAMS ARE LIKE TOPOLOGICAL CIRCUIT DIAGRAMS.

Diagramms have arrows, and diagrams also have arrows. The two
are very different, however, that in diagrams the arrows are
currents, and in diagramms they are voltages. The difference
is that in diagrams the arrows are in the direction of the
current flow, and in diagramms they are in the direction of the
voltage drop.



A signal diagram is a diagram in which the arrows are
voltage drops. The signal diagram is a diagram in which the
arrows are voltage drops. The signal diagram is a diagram in which
the arrows are voltage drops. The signal diagram is a diagram in which
the arrows are voltage drops.

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voltage drops. The signal diagram is a diagram in which the
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the arrows are voltage drops.

PLEASE READ VERY CAREFULLY.

IF YOU DO NOT UNDERSTAND ANY POINT, PLEASE RE-READ UNTIL YOU THOROUGHLY UNDERSTAND IT.

By now you know a considerable amount about linear circuits. You have studied algebraic methods used to solve linear circuits. Starting this morning, you are going to learn about signal flowgraphs. Linear flowgraphs will furnish you with a graphical method for solving linear circuits (and other linear systems).

SIGNAL FLOWGRAPHS ARE DIFFERENT FROM CIRCUIT DIAGRAMS ALTHOUGH AT FIRST SIGHT YOU MAY THINK THEY ARE LIKE TOPOLOGICAL CIRCUIT DIAGRAMS.

Flowgraphs have branches with arrows, and flowgraphs also have nodes. You must keep firmly in mind, however, that in flowgraphs NODES REPRESENT SIGNALS (voltages, currents, etc.). Nodes thus have a different meaning than heretofore. THE ARROWS ON BRANCHES IN FLOWGRAPHS MEAN THAT A SIGNAL CAN TRAVEL ONLY IN THE DIRECTION INDICATED.



A signal enters the flowgraph at the node labelled e_1 -- since nodes represent signals, e_1 might stand for a voltage. Then this signal travels only in the direction indicated by the arrow. Signals cannot flow against the arrow. Thus arrows have a different meaning than heretofore.

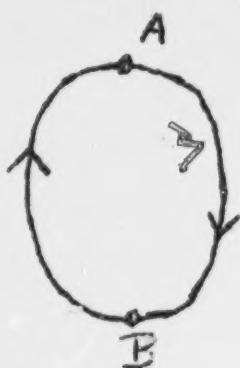
Since nodes are defined in a new way, what happens at nodes in flowgraphs is not what happens at nodes in circuit diagrams. In particular, as you will see later, the signal at a node is given by the sum of all the incoming signals, but this same node signal is transmitted out identically over all the outgoing branches. It is rather like pressure in a liquid in this regard. If a

node represents a voltage, that voltage is transmitted out over all the outgoing branches. Thus there is not Kirchhoff's law for nodes in a signal flowgraph, but rather a different rule applies.

Also flowgraphs may contain loops, and at first you are apt to mistake them for the kinds of loops you have seen in topological graphs of circuits. They are a different kind of loop. Rather than counting "windows" as you have with circuit diagrams, you will be counting all possible closed paths as different loops, traveling with the arrows. You will soon learn, for instance, that the graph on the left below contains two loops, viz:



Original flowgraph



Loop 1



Loop 2

The right-hand portion of the graph, i.e.,



is not a loop because you cannot travel all the way around it in the directions shown by the arrows.

To sum up: signals flowgraphs are easy to learn and easy to apply to linear system problems. In what follows you will learn about nodes, branches, directions of branches, and loops, but THESE TERMS MEAN QUITE DIFFERENT THINGS FROM WHAT THEY HAVE MEANT IN CIRCUIT DIAGRAMS. Further more, the rules for

manipulating flowgraphs are different. You will have to be alert for these differences, and carefully distinguish what you will now learn from what you have previously learned about circuit diagrams.

Please try to keep in mind, as you study what follows, that flowgraphs employ the same terms as circuit diagrams, but that the meanings of these terms are completely different.

INTELLIGENCE SYSTEMS AND DESIGN EX-17

EXPERIMENTAL EXPERIMENT NO. 4

Test Booklet for Experiment II

Print your name above in the space provided and write "Yes" or "No" in the
next space depending upon whether you have previously studied algebra. (Remember

DO NOT OPEN THIS BOOKLET UNTIL TOLD TO DO SO.

In the next column fill in the blank, always writing
YES or NO as directed and never anything else.

INTRODUCTORY SYSTEMS AND DESIGN 52.17

EDUCATIONAL EXPERIMENT NO. 4

NAME _____

PREVIOUS FLOWGRAPHS? _____

Print your name above in the space provided, and write "Yes" or "No" in the next space depending upon whether you have previously studied signal flowgraphs.

DO NOT OPEN THIS BOOKLET UNTIL TOLD TO DO SO.

As you work through this booklet, please do not return to questions you have answered earlier.

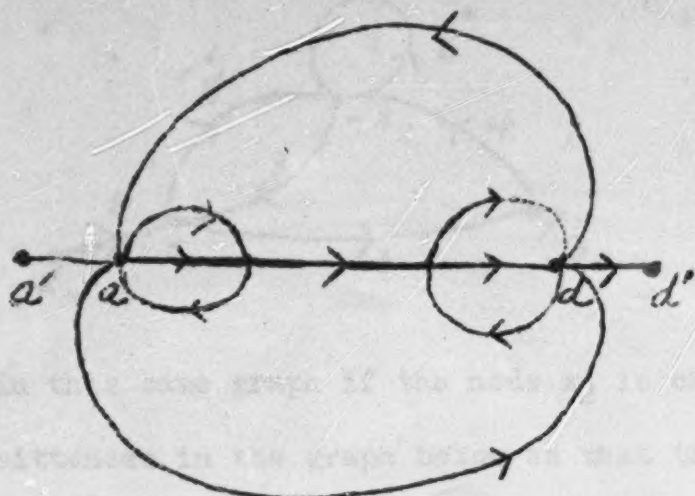
source transmittance dependent branches loop scalar multiplied
signals nodes transformation observable

PLEASE FILL IN BLANKS IN QUESTIONS BY USING WORDS FROM THE SELECTION GIVEN ABOVE.

- 1) A node with no incoming branches is a _____ node.
- 2) A closed path which begins and ends on the same node and encounters no node more than once is called a _____.
- 3) In using signal flowgraphs, voltages and currents are represented by _____.
- 4) In signal flowgraphs, operators are represented by _____.
- 5) The output signal value divided by the input signal value of a branch is the branch _____.
- 6) In signal flowgraphs signals are represented by _____.
- 7) A directed branch in a flowgraph represents the _____ necessary to convert the signal(s) at one (or more) node(s) into the signal at another node.
- 8) Nodes with one or more incoming branches are _____ nodes.
- 9) In flowgraphs, signals may represent any _____.

10) In the graph shown at the left below:

Circle the right number



a) How many loops are there? 3

4

5

6

9

10

b) How many open paths are 0

there from a' to d'? 1

2

3

4

5

c) How many open paths are 0

there from d' to a'? 1

2

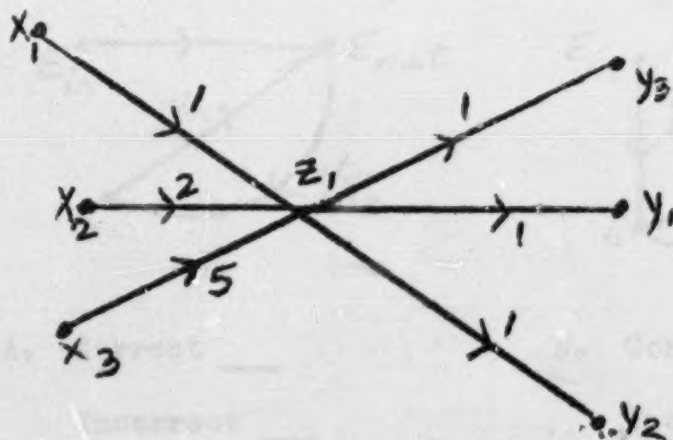
3

4

5

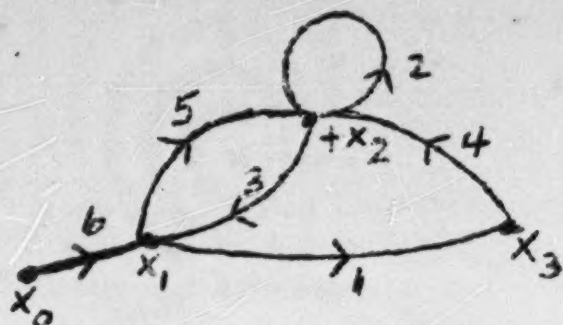
11) What is the value of the signal y_1 in the graph below?

Answer: _____

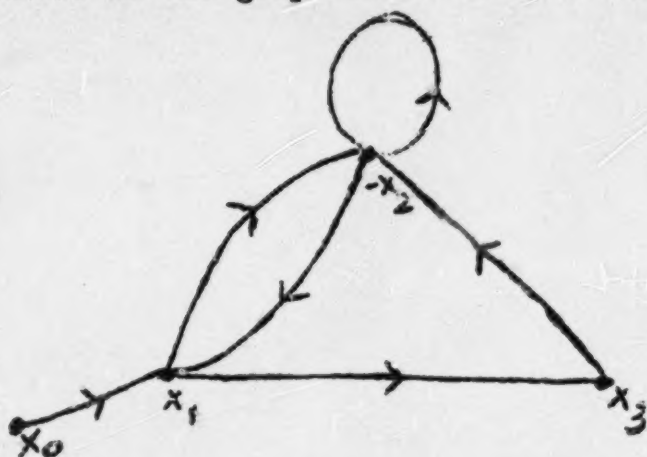


12) How many loops are there in the graph shown below?

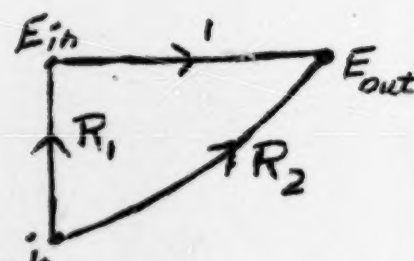
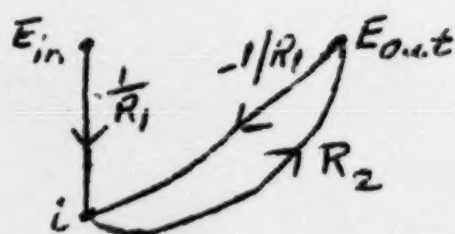
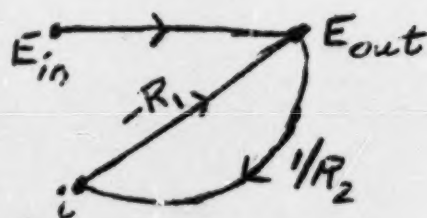
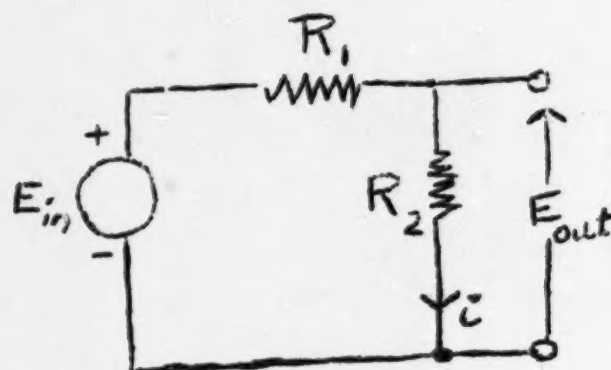
Answer: _____



In this same graph if the node x_2 is changed to $-x_2$, label the branch transmittances in the graph below so that the values of x_1 and x_3 will be unchanged.



13) Determine which of the flowgraphs shown below are correct statements of the signal relationships in the simple voltage divider shown at the right:



A. Correct _____
Incorrect _____

B. Correct _____
Incorrect _____

C. Correct _____
Incorrect _____

INTRODUCTORY SYSTEM AND METHOD - 1912

EDUCATIONAL EXPERIMENT No. 3

WRITE YOUR NAME: _____

Read the instructions on the next page carefully. The material you will be

reading today is adapted from **Booklets for Experiment III** should work some of the

individually. After you have finished a section, you are requested not to

return to it. You are also requested not to look ahead to a new section before

you finish

INTRODUCTORY SYSTEMS AND DESIGN - 52.18

EDUCATIONAL EXPERIMENT No. 5

PRINT YOUR NAME: _____

Read the instructions on the next page carefully. The material you will be reading today is stapled in separate sections, and you should work each section individually. After you have finished a section, you are requested not to return to it. You are also requested not to look ahead from one section to the next section.

INSTRUCTIONS

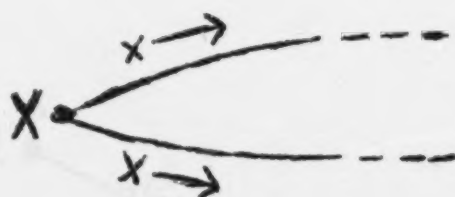
As one part of the effort to improve the teaching materials used in Introductory Systems and Design, we are analyzing the self-teaching materials on flowgraphs (Adaptive Teaching Texts I and II which you will receive shortly). In the attached materials, you will see that there are several small self-contained sections of text. At the end of each section, you are asked to answer a question, or series of questions. Your answers to these questions will not be graded. Rather your answers will help us discover weak points in the text, or will indicate where additional explanation is needed. After you have written an answer, please put the section aside. When you start a new section, the answer for the preceding section will be given and explained, so that any misunderstandings will be corrected before you go on. Please do not look ahead and consult these answers which are supplied, however, because that would defeat the purpose of this experiment. We need your first answer if your answers are to help us improve this material. There is no time limit, but do not spend more than 2-3 minutes on the answer to any section. If you cannot answer within that time, write "No time".

SECTION I - Page 1

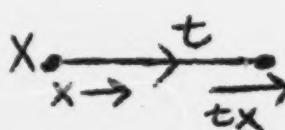
TRANSFORMATIONS AND REDUCTIONS OF SIGNAL FLOW-GRAPHS

Any problem involving simultaneous linear relationships among a number of signals can be expressed in flow-graph form. In these notes we will show how problems of this kind can be solved directly by inspection of the graph without the necessity for manipulating algebraic equations. Since these flowgraph techniques will be equally applicable to many other linear problems, we shall use a general notation for the signals and transmittances.

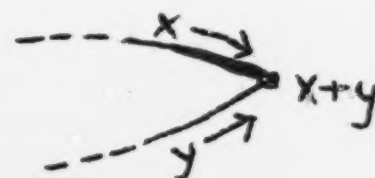
The fundamental rules for interpreting a flowgraph are illustrated by the three diagrams below.



(a)



(b)



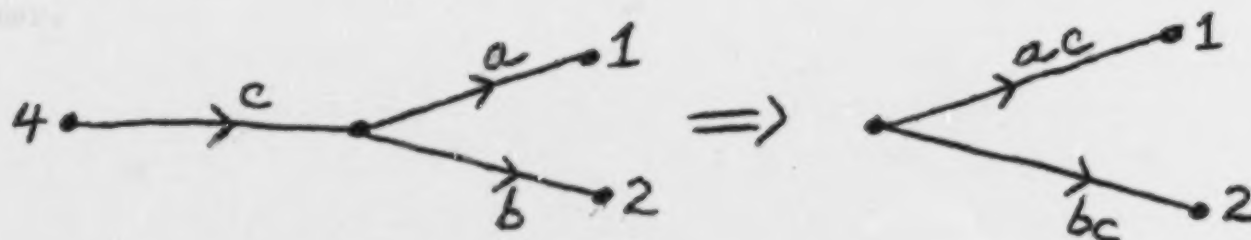
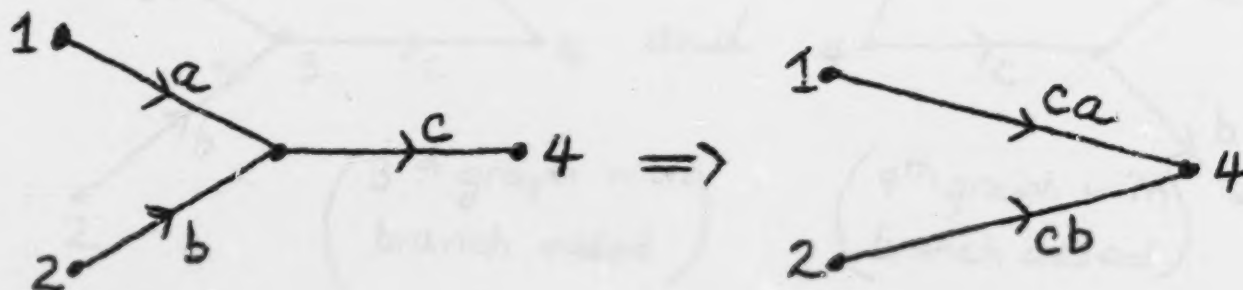
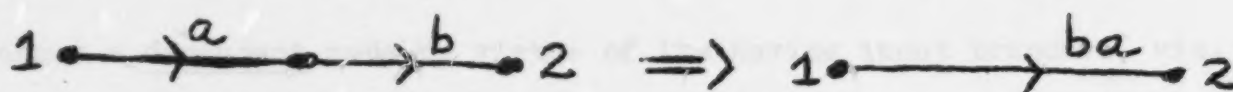
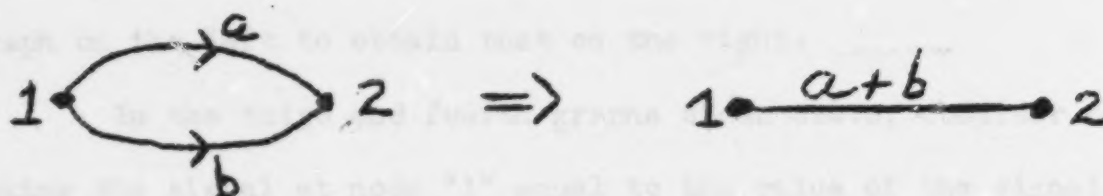
(c)

Diagram (a) shows that the signal represented by a node serves as the input for each branch radiating away from that node. Diagram (b) shows that, as the signal is transmitted over a branch, it is multiplied by the branch transmittance t . Diagram (c) shows that the value of a signal at a node is equal to the total signal received by that node.

Section I - Page 2

Elementary Transformations

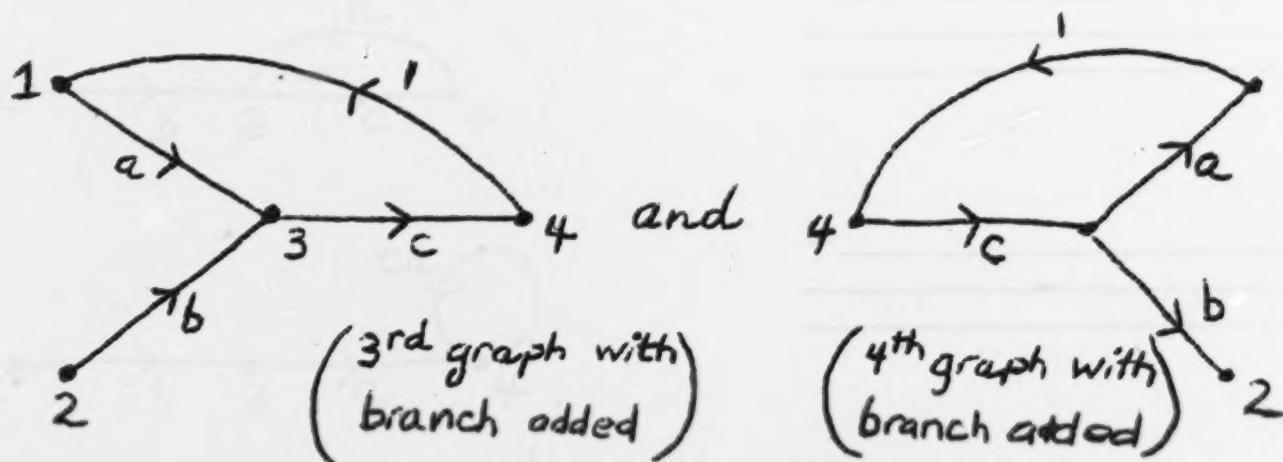
A number of elementary transformations follow directly from these rules which permit reduction and simplification of a graph. These are;



SECTION I - Page 3

The validity of these transformations may be proven easily by showing that a given source signal will produce the same signal values at the sink nodes in either graph. Clearly, the last three graphs are equivalent only for the retained nodes, node "3" having been absorbed in the process of transforming the graph on the left to obtain that on the right.

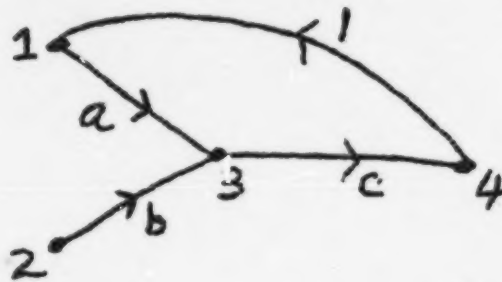
In the third and fourth graphs shown above, consider next the effect of making the signal at node "1" equal to the value of the signal at node "4". This may be accomplished in flowgraph symbolism by drawing from node "4" to node "1" a branch having unity transmittance; node "1" thus ceases to be a source and becomes a dependent node by virtue of its having input branches, viz.



By using the elementary transformations described above, it is now possible to absorb nodes and contract each of these "single-loop" graphs to simpler forms. Shown on the following page are several transformed graphs obtained in this manner.

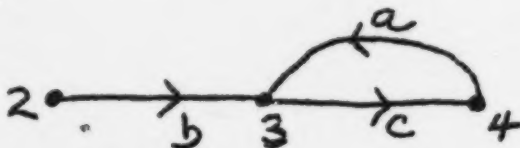
SECTION I - Page 4

Check the reduced graphs and if you think any are incorrect, state the reason for the incorrectness in the space provided.

Original GraphReduced graphs

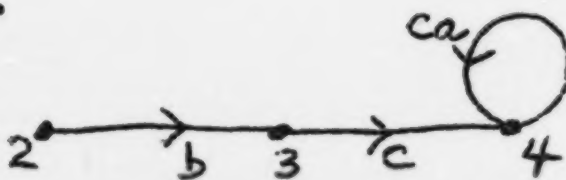
If the reduced graph is not equivalent to the original graph, state why.

1.



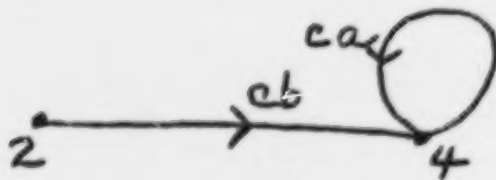
1. _____

2.



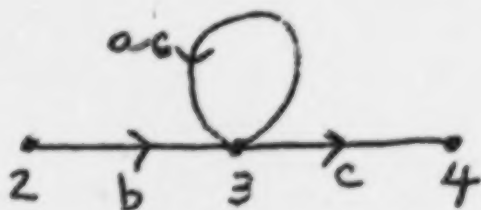
2. _____

3.



3. _____

4.



4. _____

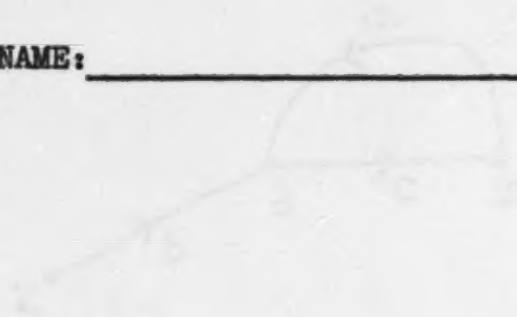
SECTION II - Page 1

The first reduced graph is equivalent, because the only change is that node "1" is absorbed into the set of nodes of the path containing node "2" so node "5" is unchanged.



Original graph

YOUR NAME: _____



First reduced graph

The second reduced graph may be obtained by removing the same loop with the original graph. It may

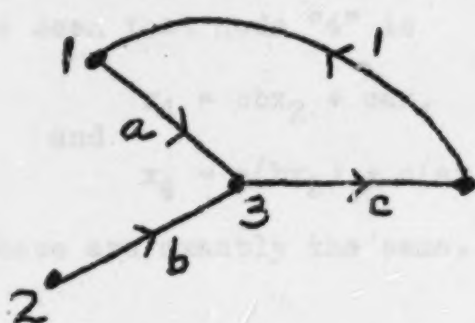
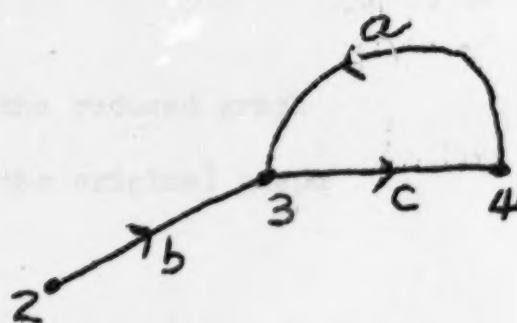


Second reduced graph

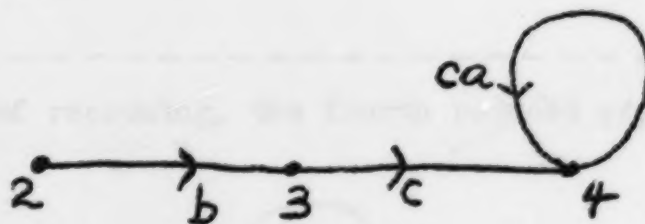
In this graph the total signal flow into node "1" is zero, because there is no loop. The loop containing node "1" is now part of the path starting at node "2". This change is made from the signal at node "2" in the original graph, because the signal at node "2" is zero in the original graph. Therefore, the second reduced graph is equivalent.

SECTION II - Page 2

The first reduced graph is equivalent, because the only change is that node "1" is absorbed, but the transmittance of the path connecting node "4" to node "3" is unchanged.

Original graph $\Rightarrow$ First Reduced Graph

The second reduced graph may be compared in the same way with the original graph. It was:

Second Reduced Graph

In this graph the total signal flow into node "3" is bx_2 , because there is only one branch terminating on node "3". This clearly differs from the signal at node "3" in the original graph, because the signal at node "3" is seen to be $bx_2 + ax_4$. Therefore, the second reduced graph is incorrect.

SECTION II - Page 3

The third reduced graph is correct, because although node "3" has been absorbed (and therefore the graph does not make any statements about it), the remaining nodes have the same values as in the original graph. In particular, it can be seen that node "4" is

$$x_4 = cbx_2 + cax_4$$

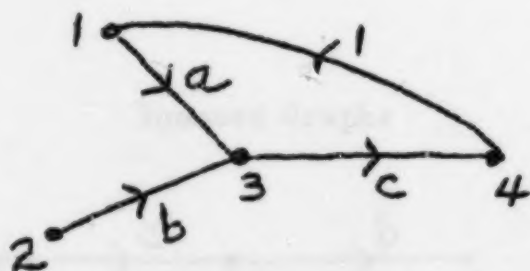
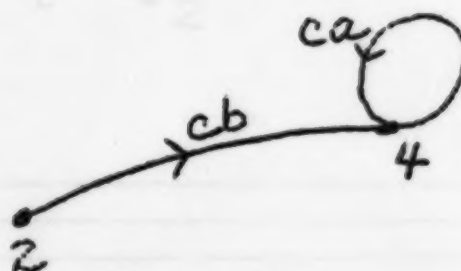
and

$$x_4 = c(bx_2) + c(ax_4)$$

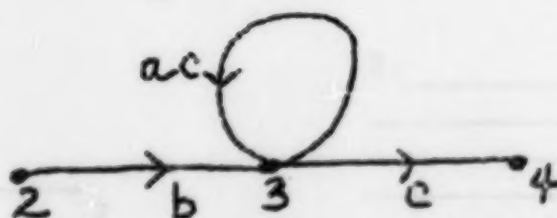
for the reduced graph

for the original graph

and these are exactly the same.

Original GraphThird Reduced Graph

By a similar process of reasoning, the fourth reduced graph

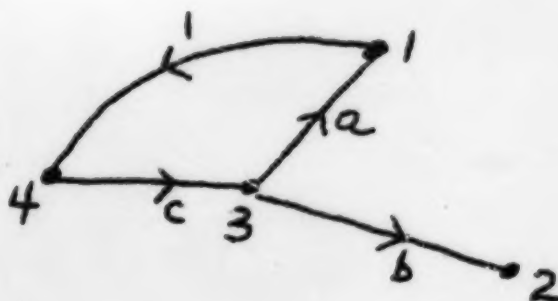


has equivalent signals for corresponding nodes of the original graph.

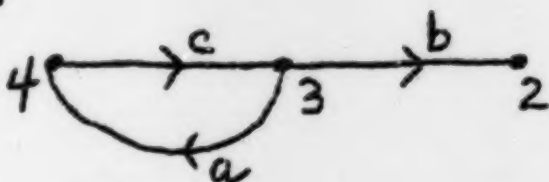
IF ANY ONE OF THESE REDUCED GRAPHS OR THEIR EXPLANATIONS ARE UNCLEAR, PLEASE WRITE IN THIS BOOK WHAT YOUR DIFFICULTY IS.

SECTION II - Page 4

Check the reduced graphs shown below, and if you think any are incorrect, state the reason for the incorrectness in the space provided.

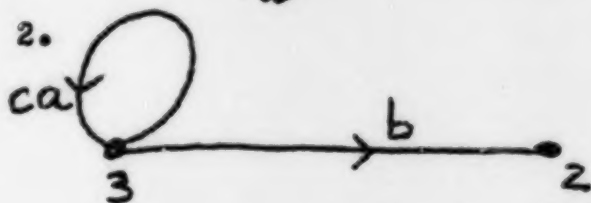
Original GraphReduced Graphs

1.



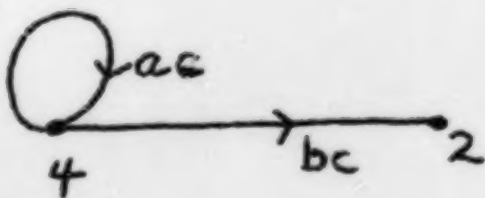
1.

2.



2.

3.

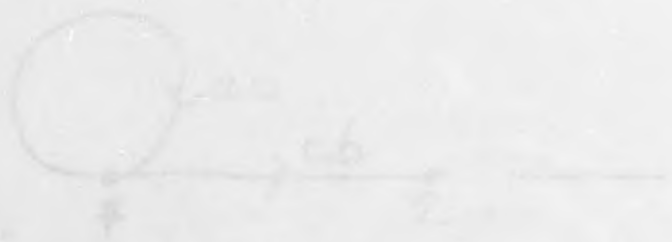


3.

SECTION III - Page 1

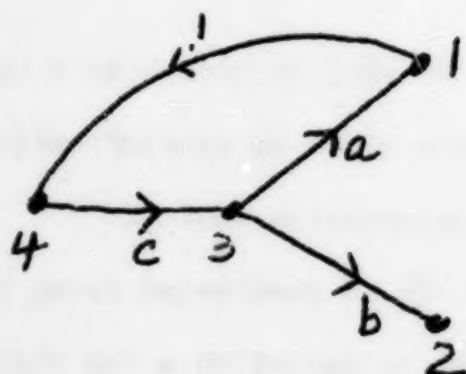
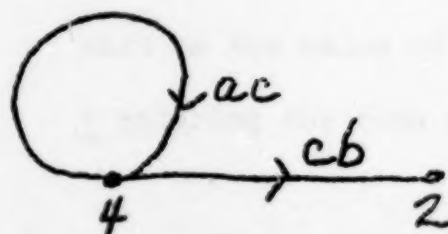
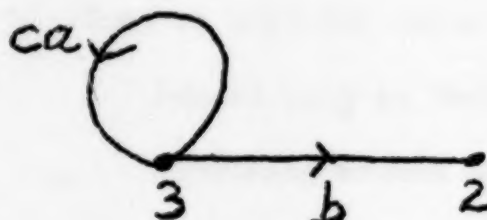
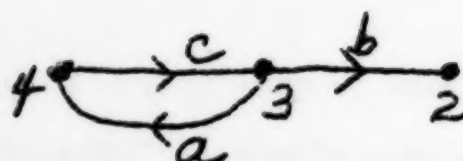
All the reduced graphs in this set are equivalent representations of the original graph. They are represented below, and it is still assumed that the vertices are labeled as in the original graph.

YOUR NAME: _____

Original GraphReduced Graphs

SECTION J.II - Page 2

All the reduced graphs in this set were equivalent representations of the original graph. They are reproduced below, and if you still cannot see the equivalence, check the space provided.

Original GraphReduced Graphs

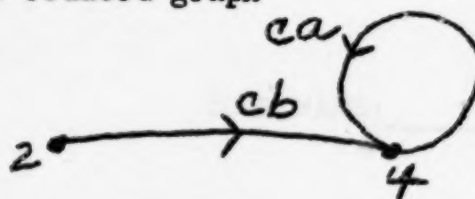
Check

?

SECTION III - Page 3

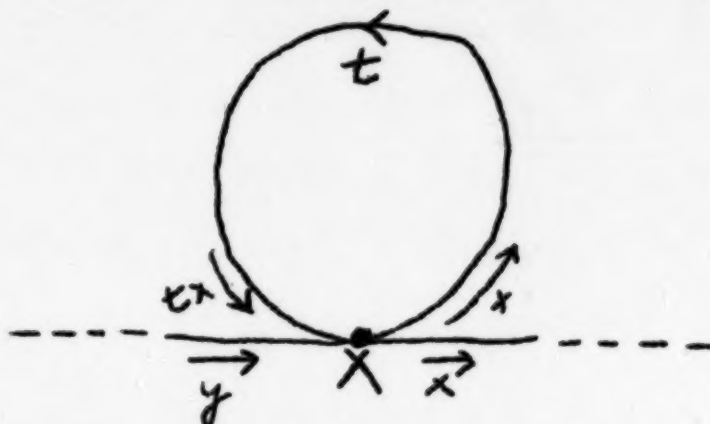
Effect of Self-Loops

In some of the reduced graphs previously considered, there appeared self-loops. For instance, one reduced graph



had a self-loop on node "4". A self-loop begins and ends on the same node, and passes through no other node.

A clear understanding of the effect of a self-loop at some node will be of great importance in all that follow. Consider the single node shown below which has a self-loop of transmittance $\underline{t}$. Suppose that the value of the node



signal is $\underline{x}$ so that the signal returning around the self-loop is $\underline{tx}$. For this condition, what must be the value of the signal $\underline{v}$ entering the node from the left?

ANSWER _____

Remember: A signal of value $\underline{x}$ is coming out of the node, and a signal $\underline{v}$ plus a signal $\underline{tx}$ (from the self-loop) are entering the node.

SECTION IV - Page 1

The correct answer is

$$y = (1 - \frac{1}{2})x$$

Part of the input signal is produced by the signal x and the other part is produced by the signal y . If the output is z , then $z = x + y$. If the output is z , then $z = x + y$. If the output is z , then $z = x + y$.

YOUR NAME: _____

If you do not know the answer, write what you think.

The quantity $(1 - \frac{1}{2})x$ is called the output in the system. In fact, when $t = 1$, the output is $z = x + y$. The quantity $(1 - \frac{1}{2})x$ is called the output in the system. In fact, when $t = 1$, the output is $z = x + y$. The quantity $(1 - \frac{1}{2})x$ is called the output in the system. In fact, when $t = 1$, the output is $z = x + y$. The quantity $(1 - \frac{1}{2})x$ is called the output in the system. In fact, when $t = 1$, the output is $z = x + y$.

SECTION IV - Page 2

The correct answer is

$$y = (1 - t)x$$

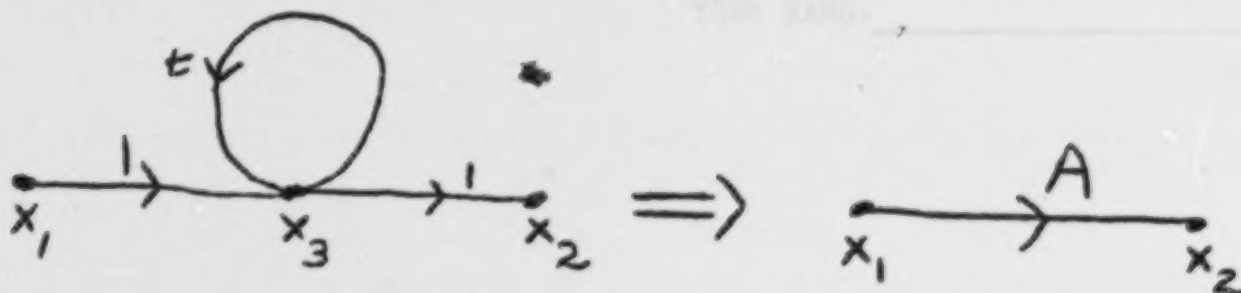
Part of the input needed to produce an output of x is produced by the signal x itself. If the output is x, and tx is being supplied by the self-loop, then only $x - tx$ is needed from the source.

If you do not understand this, write here what is unclear.

The quantity $(1 - t)$ is called the return difference in feedback theory. In fact, when $t = 1$, the return difference becomes zero, which means that all of the input signal needed to create a signal x at the node is "fed back" as a consequence of the signal itself, and no external signal at all is required to sustain the signal x. This peculiar condition governs the natural behavior of a system, and plays a vital role in the study of stability and other aspects of the dynamic behavior of linear physical systems.

SECTION IV - Page 3

Now that you have been introduced to the effect of a self-loop, you should be able to determine the equivalent transmittance of a path that contains a node having a self-loop such as the following:



The equivalent transmittance A is:

ANSWER: _____

SECTION V - Page 1

The following signal (the signal at x_2) is equal to $1/2$ of the signal

$$x_1 = \frac{1}{1-s}$$

produced by the self-loop, and is only $1/2$ of the signal from the source. In

YOUR NAME: _____

writing a transmission, as you might suppose, the output is written over the

input. Since the only signal being put out, and $(1-s)$ and $1/2$ are coming from the

source, so the transmission is $1/2(1-s)$.

The effect of a self-loop at any node is to multiply an external signal

by the factor $(1-s)$ as the signal passes through the node. This result is

valid for all values of s , since your derivation of this result was independent

of the magnitude of s .

Simple inspection of this result indicates that any signal which

is sent to the signal source (the source is the source of the signal) will be



$$\frac{x_2}{x_1} = \frac{1}{1-s} \cdot \frac{1}{2} = \frac{1}{2(1-s)}$$

although there is only one path from x_1 to x_2 , there are multiple paths

of signals (the signal at x_2 is $1/2$ of the signal from the source) and the following

some additional paths have respectively the gains $1/2, 1/4, 1/8, \dots$

SECTION V - Page 2

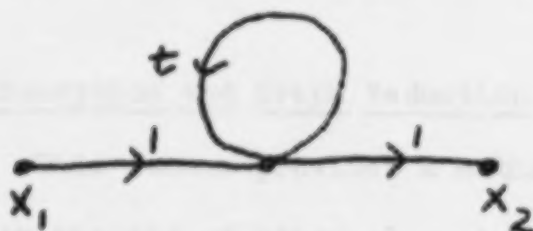
The transmittance you should have written is

$$A = \frac{1}{1-t}$$

Here the outgoing signal (the signal at x_2) is equal to 1. " t " of ~~this is being~~ supplied by the self-loop, and so only $1 - t$ is needed from the source. In writing a transmittance, as you might suppose, the output is written over the input. Here one unit is being put out, and $(1 - t)$ units are coming from the source, so the transmittance is $1/(1 - t)$.

The effect of a self-loop at any node is to multiply an external signal by the factor $(\frac{1}{1-t})$ as the signal passes through the node. This result is valid for all values of t , since your derivation of this result was independent of the magnitude of t .

Another interpretation of this result considers the many different routes by which the signal can find its way from the source x_1 to the dependent node x_2 .



$$\begin{aligned} \frac{x_2}{x_1} &= 1 + t + t^2 + t^3 + \dots \\ &= \frac{1}{1-t} \end{aligned}$$

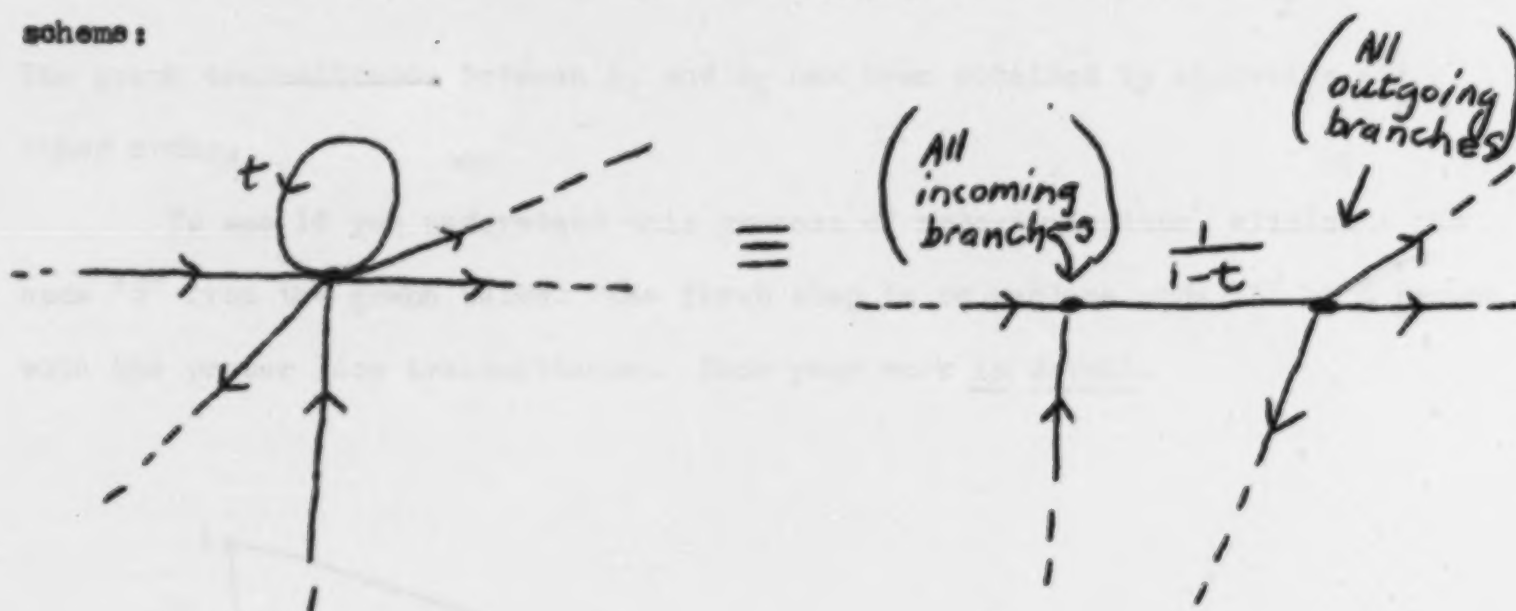
Although there is only one open path from x_1 to x_2 , there are an infinite number of paths (corresponding to 0, 1, 2, 3, ... circulations around the self-loop).

These successive paths have respectively the transmittances $1, t, t^2, t^3, \dots$

SECTION V - Page 3

Since the paths are all originating from x_1 and terminating on x_2 , they are all effectively in parallel and the sum of the transmittances yields the infinite geometric series which sums to $\frac{1}{1-t}$, and thus agrees with our previous result.

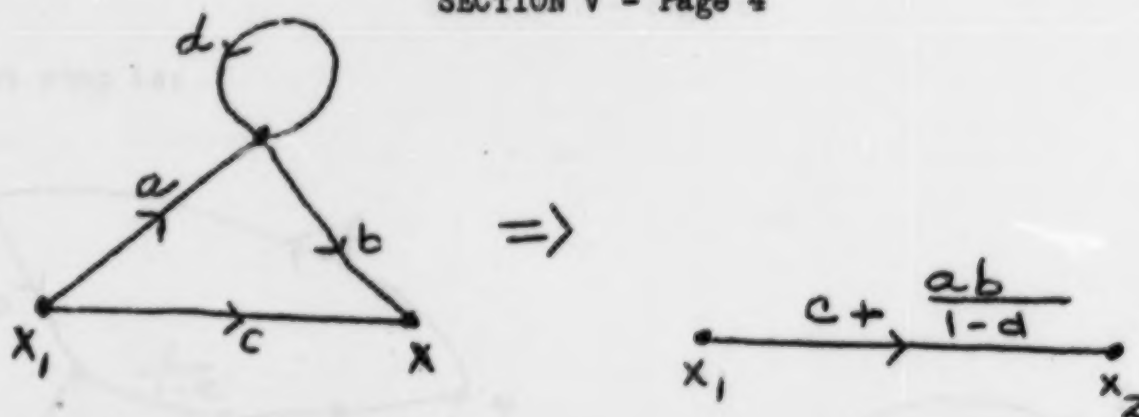
When several branches enter and leave the node, it is helpful to replace the node by a branch having a transmittance $\frac{1}{1-t}$ according to the following scheme:



Node Absorption and Graph Reduction

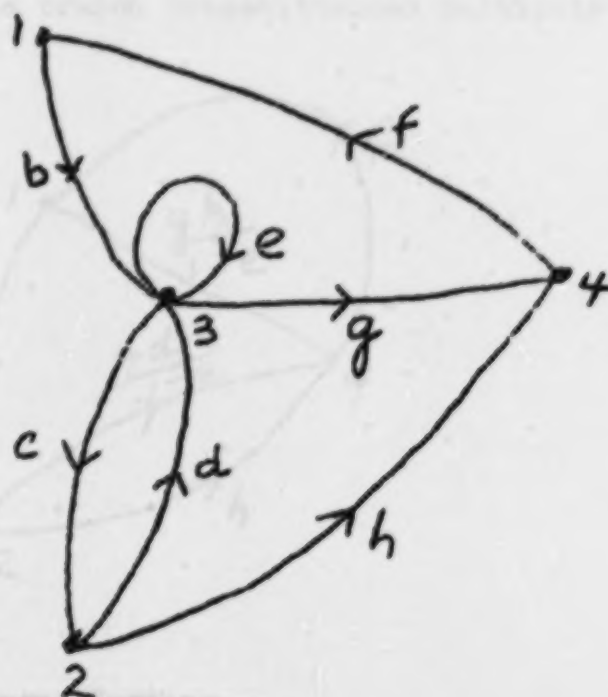
This scheme provides a method for absorbing nodes that have a self-loop, and with the aid of other elementary transformations already given, any node in a graph can now be absorbed. This is illustrated in the following example.

SECTION V - Page 4



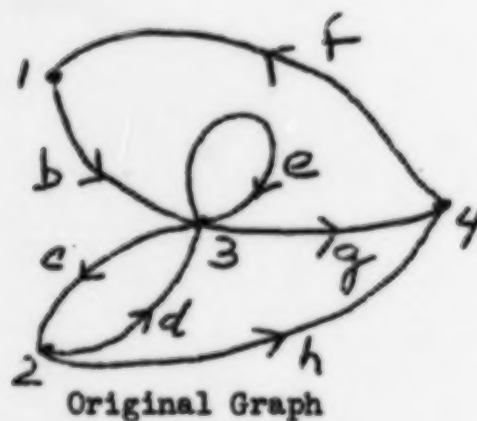
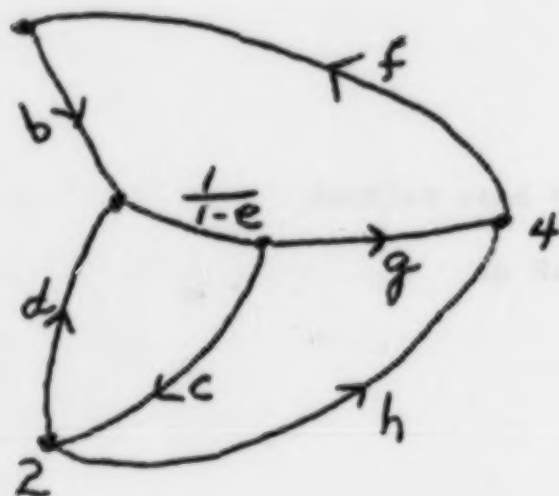
The graph transmittance between x_1 and x_2 has been obtained by absorbing all other nodes.

To see if you understand this process of node-absorption, eliminate the node "3" from the graph below. The first step is to replace node "3" by a branch with the proper loop transmittance. Show your work in detail.

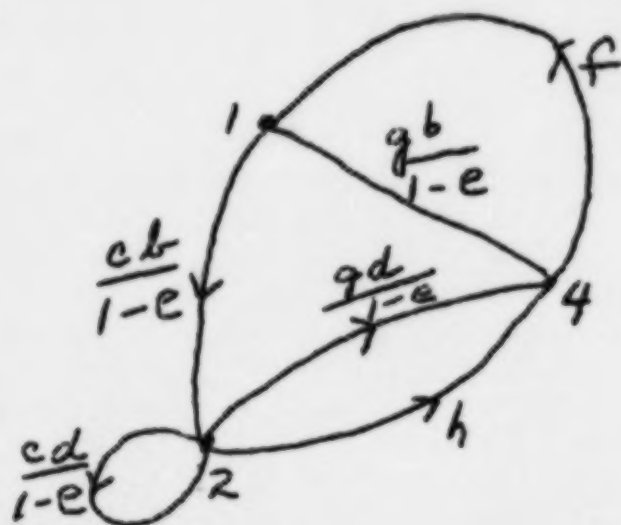


SECTION V - Page 5

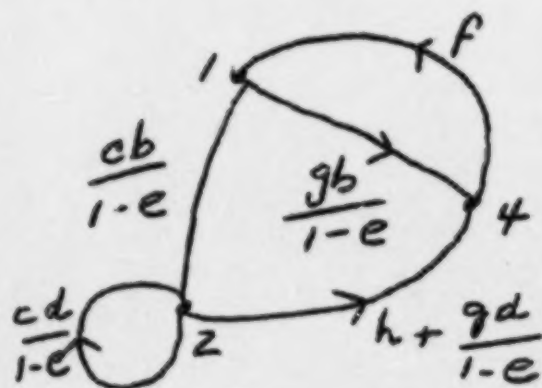
The first step is:



Now if the points representing the former node "3" are ignored, and the appropriate branch transmittances multiplied, we have



or simplifying further



If your result did not agree with this one, and you cannot see why, write here what seems unclear to you.

This image shows a single sheet of white paper with horizontal blue or grey ruling lines. The lines are evenly spaced and run across the width of the page. There is no handwriting or other markings on the paper.

The following questions are asked in the

questionnaire: 1. How many times

A. 1

in English, a sentence translated in

A. 2

condition is followed by **Booklet used by Experimental Group**

condition is followed by **in Experiment IV**

condition is followed by

condition is followed by

IN THIS BOOKLET SEVEN QUESTIONS ARE
THE NUMBER ANSWERS TO THE SEVEN
QUESTIONS. AFTER THE SEVEN QUESTIONS THE
THE PAID TO SEE THE QUESTIONS ANSWERED

Answers in English:

1) "X plus Y equals Z" 2)

2) "X divided by Y" 3)

3) "Y multiplied by Z" 4)

4) "Y multiplied by reciprocal of Z" 5)

In writing FORTRAN all letters are written in capitals. If you have

$$a + b$$

in algebra, a FORTRAN translation is

$$A + B$$

Addition is indicated by +

Subtraction is indicated by -

Multiplication is indicated by *

Division is indicated by /

IN THIS BOOKLET WRITE ANSWERS OPPOSITE THE NUMBER APPEARING IN THE RIGHT MARGIN. AFTER YOU HAVE ANSWERED TURN THE PAGE TO SEE THE CORRECT ANSWER

Write in Fortran:

- | | |
|--------------------------------------|----|
| 1) "X plus Y minus Z" | 1) |
| 2) "A divided by B" | 2) |
| 3) "C multiplied by D" | 3) |
| 4) "M multiplied by reciprocal of N" | 4) |

$X + Y - Z$

1)

A/B

2)

$C * D$

3)

M/N or $M * 1/N$

4)

No operation is taken for granted.

Thus C multiplied by E must be written

$$C * E$$

An equal sign, =, means: "Replace the quantity on the left by what is on the right".

Exponentiation is indicated by ** followed by a digit indicating the power to which the base is raised. For example, A**3 means "A cubed". Subscripts are indicated by being enclosed in parentheses immediately following the variable they are appended to. Thus A_i in conventional notation is A(I) in FORTRAN.

Double subscripts are written with a comma between subscripts, and both subscripts within one set of parentheses. A_{ij} in FORTRAN is A(I,J). Write in FORTRAN:

- | | |
|-----------------------------------|----|
| 1) "C squared" | 1) |
| 2) "A multiplied by B squared" | 2) |
| 3) "B subscripted with a J" | 3) |
| 4) "X = Y ³ " | 4) |
| 5) " $A_i = \frac{B_{ij}}{2.5}$ " | 5) |

$C * C$ or $C ** 2$

1)

$A * B ** 2$

2)

$B(J)$

3)

$X = Y ** 3$

4)

$A(I) = B(I, J) / 2.5$

5)

The use of parentheses to indicate order of operations (quantities within parentheses being evaluated first) is exactly like algebraic notation. Thus if you wish to translate from algebra

$$X = (Y/1.1)^3$$

you write in FORTRAN

$$X = (Y/1.1)**3$$

If you omitted parentheses in above expression, only the denominator would be cubed.

As mentioned before, no operation is taken for granted: all operations must be explicit. Thus, parentheses do not imply multiplication, nor do symbols written directly in series imply multiplications. $A(I)$, as already stated, does not mean A multiplied by I -- it means A_i . ABC does not mean A multiplied by B multiplied by C -- it means instead a single variable named "ABC". (Variables are often designated with more than one letter -- for example you can write INCR to label a variable.) If you want to multiply A by B by C, you must say

$$A * B * C$$

No two operation symbols can appear side by side. Thus if you wish to divide A by -B, you must write the quotient as

$$A/(-B)$$

using parentheses to separate the division sign from the sign of the denominator.

You also use parentheses to enclose exponents when needed. If you wish to translate

$$A^{I-2}$$

you write

$$A**(I-2)$$

because (I-2) is the power to which A is raised. If you erroneously wrote $A**I-2$ you would have implied $A^I - 2$.

Write in FORTRAN:

- | | |
|---------------------------------------|----|
| 1) "B multiplied by A_1 " | 1) |
| 2) $\frac{2.1A}{C^2}$ | 2) |
| 3) $\frac{C^X + A}{-B}$ | 3) |
| 4) $A = \left(\frac{B^4}{C}\right)^n$ | 4) |
| 5) $\frac{X_{ij}}{C}$ | 5) |

$B=A(I)$ 1)

$2.1*A/C**2$ 2)

Notice here no parentheses are around denominator, because exponentiation is carried out prior to any other operation. "Extra" parentheses may prevent your program from running.

$C=(X+A)/(-B)$ 3)

$A = (B/C)**4$ 4)

Here parentheses are needed.

$X(I,J)/C$ 5)

Operations are carried out in the same order as algebra. Exponentiation is carried out first, then multiplication and division, then addition and subtraction. For instance, if you evaluate by hand, for $A = 3$

$$= 2.0A^2 + 3.0$$

you first square A ($3^2 = 9$), then multiply A^2 by its coefficient (yielding 18), then add 3 to obtain 21.

In FORTRAN you write

$$2.0*A**2 + 3.0$$

and the operations of exponentiation, multiplication and addition are carried out successively. If all operations within an expression are of the same "precedence", they are carried out in order written. For example

$$A*B/C$$

is computed as

$$A*B$$

and the $A*B$ product is divided by C . Or

$$A - B + C$$

is computed as

$$A - B$$

and the difference is added to C . If you have

$$(A - B) * C$$

the operation within parentheses will be carried out before the remainder of the expression is evaluated. Innermost parentheses are operated upon first.

Thus,

$$(1.1 + (A - B)**2)/C$$

will cause the difference $A - B$ to be squared and the squared difference plus 1.1 to be divided by C .

In algebra often "extra" parentheses are used for no particular reason. For instance writing

$$\frac{2.0 Y}{(X^2)}$$

in algebra, it does not make any difference whether you put parentheses around the denominator or not. In 1620 FORTRAN "extra" parentheses may cause trouble during compiling. You should use the minimum number of parentheses necessary to render the expression correctly.

Translate the following in FORTRAN:

$$1) \quad X = \frac{A - B - C^2}{2.1 - Y} \quad 1)$$

$$2) \quad X = \frac{-B - B^2 - 4.0AC}{2.0A} \quad 2)$$

$$3) \quad E = C(R_1 + R_2 + R_3) \quad 3)$$

$$X = (A - B - C**2)/(2.1 - Y) \quad 1)$$

Parentheses needed around denominator.

$$X = (-B - B**2 - 4.0*A*C)/(2.0*A) \quad 2)$$

Parentheses needed around denominator.

Without parentheses around the

denominator A would be used as a multiplier instead of a divisor.

$$E = C*(R(1) + R(2) + R(3)) \quad 3)$$

You had no way of knowing it, but so far some other rules have been observed in writing arithmetic expressions. These rules have to do with "floating-point" and "fixed-point" modes.

"Modes" relate to the decimal point. A computer needs to be notified when quantities are not integers. In computational problems, it is rare that all quantities are whole numbers, and consequently, we need some method of telling the computer how to align decimal points. In adding two quantities by hand you write:

$$\begin{array}{r} 10.5432 \\ \underline{0.5643} \end{array}$$

lining up decimal points, and then take the sum. If you use a desk calculator, it treats all quantities you insert as integers -- you, the operator, take over the job of determining where the decimal point should fall. A digital computer can take over the task of keeping track of decimal points, but it will do this only if you tell it. You tell it by the way you write your expressions.

If you want to write anything but integers from -99999 to +99999, you must use floating point. A floating point number has to be written with a decimal point inserted. The decimal point may appear at the beginning, at the end, or in the middle of the number, but it must appear somewhere.

- 1) Write one hundred as a floating point number. 1)
- 2) Write two as a floating point number. 2)
- 3) Write zero as a floating point number. 3)
- 4) Write 10^6 as a floating point number. 4)

1) 100.0 or 10.0^{**2} or $1.0*10.0^{**2}$ 1)

2) 2. or 2.0 2)

3) 0. or 0.0 3)

4) 1000000.0 or 1000000. or
10.0**6 or $.1*10.0^{**7}$ 4)

If you got number one or four wrong,
be sure you understand why before
proceeding.

A fixed point number is an integer and no decimal point appears in it. When the computer reads a number, it takes any number containing a decimal point as a floating point number, and any number without a decimal point as fixed-point.

Plus or minus signs may be attached to any number, fixed or floating-point. A negative quantity must be preceded by a minus sign, but use of a plus sign is optional. Thus +3.14 is the same as 3.14.

All quantities on one side of an equal sign must be of the same mode with the exception of exponents and subscripts. This is a very important restriction. Thus, if you wish to write "Replace X by twice 3.2" you must say

$$X = 2.0 * 3.2$$

inserting a decimal point with "2" so that the mode of both quantities to the right of the equal sign is the same.

Subscripts must be fixed point numbers. Exponents may or may not be fixed point numbers. Thus

$$A^2$$

may be written as

$$A^{**2}$$

or

$$A^{**2.0}$$

A subscript must be written as A(2) -- not A(2.0).

1) Write one hundred as a fixed point
number. 1)

2) Write $\sqrt{3.14}$ 2)

3) What is wrong with 3)

$X = 3.14 * Y / (2 * B)$

4) What is wrong with 4)

$A(2.0)**3$

5) Write in FORTRAN "Replace Y by 5)

three and one half times X

divided by B squared".

1) (no decimal point) 100 1)

2) $3.14^{*.5}$ or $3.14^{*0.5}$ 2)

3) 2 must be floating point 3)

$X = 3.14 * Y / (2.0 * B)$ -- Parentheses
around denominator necessary.
Otherwise, it will not be
correctly divided by both two and B.

4) $A(2.0)$ is not equivalent to 2.0 4)
multiplied by A. The quantity
 2.0 in parentheses is illegiti-
mate as a subscript because it
is floating point -- all sub-
scripts must be fixed point.
 $(A_2)^3$ would be $A(2)^{*3}$
A times 2 cubed would be $A * 2.0^{*3}$

5) $Y = 3.5 * X / B^{*2}$ 5)

or $Y = 3.5 * X / B^{*2.0}$

No parentheses around numerator
or denominator.

Booklet used by Control Group

in Experiment IV

NAME: _____

PREVIOUS PROGRAMMING: _____

When writing a computer program for the computers at this University, you write in a language called FORTRAN. This language resembles algebra closely, but there are some differences. You will learn how to write computer programs using FORTRAN in this course. As part of our effort to improve teaching, we want you to learn something about FORTRAN arithmetic by using this experimental booklet.

Please do not turn to the next page until you are told to do so. Please print your name above in the space provided, and if you have had prior experience with computer programming, write "Yes" after "PREVIOUS PROGRAMMING". If not, write "No".

In writing FORTRAN all letters are written in capitals. If you have

$$a + b$$

in algebra, a FORTRAN translation is

$$A + B$$

Addition is indicated by +

Subtraction is indicated by -

Multiplication is indicated by *

Division is indicated by /

READ ALL EXAMPLES CAREFULLY

To write:

"X plus Y minus Z" in FORTRAN you write $X + Y - Z$.

"A divided by B" in FORTRAN you write A/B .

"C multiplied by D" in FORTRAN you write $C*D$.

"M multiplied by the reciprocal of N" in FORTRAN you write M/N or $M*1/N$

No operation is taken for granted. Thus C multiplied by E must be written

$$C * E$$

An equal sign, =, means: "Replace the quantity on the left by what is on the right".

Exponentiation is indicated by ** followed by a digit indicating the power to which the base is raised. For example, A**3 means "A cubed". Subscripts are indicated by being enclosed in parentheses immediately following the variable they are appended to. This A_i in conventional notation is A(I) in FORTRAN.

Double subscripts are written with a comma between subscripts, and both subscripts within one set of parentheses. A_{ij} in FORTRAN is A(I,J).

To write:

"C squared" in FORTRAN you will write C**2

"A multiplied by B squared" in FORTRAN you write A*B**2

"B subscripted with a J" in FORTRAN you write B(J)

" $X = Y^3$ " in FORTRAN you write $X = Y**3$

" $A_i = \frac{B_{ij}}{2.5}$ " in FORTRAN you write $A(I) = B(I,J)/2.5$

The use of parentheses to indicate order of operations (quantities within parentheses being evaluated first) is exactly like algebraic notation. Thus if you wish to translate from algebra

$$X = (Y/1.1)^3$$

you write in FORTRAN

$$A = (Y/1.1)**3$$

If you omitted parentheses in above expression, only the denominator would be cubed.

As mentioned before, no operation is taken for granted: all operations must be explicit. Thus, parentheses do not imply multiplication, nor do symbols written directly in series imply multiplications. $A(I)$, as already stated, does not mean A multiplied by I -- it means A_I . ABC does not mean A multiplied by B multiplied by C -- it means instead a single variable named "ABC". (Variables are often designated with more than one letter -- for example you can write INCR to label a variable.) If you want to multiply A by B by C, you must say

$$A * B * C$$

No two operation symbols can appear side by side. Thus if you wish to divide A by -B, you must write the quotient as

$$A/(-B)$$

using parentheses to separate the division sign from the sign of the denominator.

You also use parentheses to enclose exponents when needed. If you wish to translate

$$A^{I-2}$$

you write

$$A**(I-2)$$

because (I-2) is the power to which A is raised. If you erroneously wrote $A**I-2$ you would have implied $A^I - 2$.

To write:

"B multiplied by A_1 " in FORTRAN you write $B * A(I)$

" $\frac{2.1A}{C^2}$ " in FORTRAN you write $2.1 * A / C^2$

Notice here no parentheses are needed around the denominator, because exponentiation is carried out prior to any other operation. Extra parentheses may prevent your program from running.

" $C \frac{X+A}{-B}$ " in FORTRAN you write $C * (X + A) / (-B)$

" $A = (\frac{B}{C})^4$ " in FORTRAN you write $A = (B / C) ** 4$

Here parentheses are needed

" $\frac{X_{i,j}}{C}$ " in FORTRAN you write $X(I, J) / C$

Operations are carried out in the same order as algebra. Exponentiation is carried out first, then multiplication and division, then addition and subtraction. For instance, if you evaluate by hand, for $A = 3$

$$2.0A^2 + 3.0$$

you first square A ($3^2 = 9$), then multiply A^2 by its coefficient (yielding 18), then add 3 to obtain 21.

In FORTRAN you write

$$2.0*A**2 + 3.0$$

and the operations of exponentiation, multiplication and addition are carried out successively. If all operations within an expression are of the same "precedence", they are carried out in order written. For example

$$A*B/C$$

is computed as

$$A*B$$

and the $A*B$ product is divided by C . Or

$$A - B + C$$

is computed as

$$A - B$$

and the difference is added to C . If you have

$$(A - B) * C$$

the operation within parentheses will be carried out before the remainder of the expression is evaluated. Innermost parentheses are operated upon first. Thus,

$$(1.1 + (A - B)**2)/C$$

will cause the difference $A - B$ to be squared and the squared difference plus 1.1 to be divided by C .

In algebra often "extra" parentheses are used for no particular reason.

For instance writing

$$\frac{2.0 Y}{(X^2)}$$

in algebra, it does not make any difference whether you put parentheses around the denominator or not. In 1620 FORTRAN "extra" parentheses may cause trouble during compiling. You should use the minimum number of parentheses necessary to render the expression correctly.

The algebraic equations on the left have been translated into their FORTRAN equivalents shown to the right. READ CAREFULLY

$$A = \frac{A - B - C^2}{2.1 - Y}$$

$$X = (A-B-C**2)/(2.1-Y)$$

Parentheses are needed around denominator

$$A = \frac{-B - B^2 - 4.0AC}{2.0A}$$

$$X = (-B-B**2-4.0*A*C)/(2.0*A)$$

Parentheses needed around denominator

$$E = C(R_1 + R_2 + R_3)$$

$$E = C*(R(1) + R(2) + R(3))$$

You had no way of knowing it, but so far some other rules have been observed in writing arithmetic expressions. These rules have to do with "floating-point" and "fixed-point" modes.

"Modes" relate to the decimal point. A computer needs to be notified when quantities are not integers. In computational problems, it is rare that all quantities are whole numbers, and consequently, we need some method of telling the computer how to align decimal points. In adding two quantities by hand you write:

$$\begin{array}{r} 10.5432 \\ \underline{0.5643} \end{array}$$

lining up decimal points, and then take the sum. If you use a desk calculator, it treats all quantities you insert as integers -- you, the operator, take over the job of determining where the decimal point should fall. A digital computer can take over the task of keeping track of decimal points, but it will do this only if you tell it. You tell it by the way you write your expressions.

If you want to write anything but integers from -99999 to +99999, you must use floating point. A floating point number has to be written with a decimal point inserted. The decimal point may appear at the beginning, at the end, or in the middle of the number, but it must appear somewhere.

"One hundred" written as a floating
point number is 100.0

"Two" written as a floating point
number is 2.0

"Zero" written as a floating point
number is 0.0

"10⁶" written as a floating point number
is 1000000.0 or 1000000. or 10.0**6 or
.1*10.0**7

A fixed point number is an integer and no decimal point appears in it. When the computer reads a number, it takes any number containing a decimal point as a floating point number, and any number without a decimal point as fixed-point.

Plus or minus signs may be attached to any number, fixed or floating point. A negative quantity must be preceded by a minus sign, but use of a plus sign is optional. Thus +3.14 is the same as 3.14.

All quantities on one side of an equal sign must be of the same mode with the exception of exponents and subscripts. This is a very important restriction. Thus, if you wish to write "Replace X by twice 3.2" you must say

$$X = 2.0 * 3.2$$

inserting a decimal point with "2" so that the mode of both quantities to the right of the equal sign is the same.

Subscripts must be fixed point numbers. Exponents may or may not be fixed point numbers. Thus

$$A^2$$

may be written as

$$A^{**2}$$

or

$$A^{**2.0}$$

A subscript must be written as A(2) -- not A(2.0).

To write "one hundred" as a fixed point number you will write

100 (no decimal point)

To write $\sqrt{3.14}$ you write

3.14**5 or 3.14**0.5

$X = 3.14*Y/(2*B)$ is wrong because 2 must be written as a floating point number
 $X = 3.14*Y/(2.0*B)$

Here parentheses are needed around the denominator. Otherwise, the numerator will not be correctly divided by both 2.0 and B.

$A(2.0)**3$ is wrong because $A(2.0)$ is not equivalent to 2.0 multiplied by A. The quantity 2.0 in parentheses is illegitimate as a subscript because it is a floating point number; all subscripts must be fixed point numbers. $(A_2)^3$ would be written as $A(2)**3$.

To write in FORTRAN "Y = three and one half times X divided by B squared" you will write

$Y = 3.5*X/B**2$ or

$Y = 3.5*X/B**2.0$

No parentheses are necessary around the numerator or the denominator.

Please answer all of the following questions. If you do not know the answer, guess.

Translate to FOLGOL the following English or algebraic expressions.

1) x plus y minus z 11

2) x divided by y 12

3) x multiplied by y 13

4) $x - y - z$ 14

5) $x + y^2$ 15

6) x multiplied by y 16

7) $\frac{x+y}{z}$ 17

8) $x = (y/z)^2$ 18

9) $\frac{x+y}{z}$ 19

10) $x = y + z = w^2$ 20

11) $x = \frac{y^2 + z^2 + w^2}{v}$ 21

12) $x = \frac{y^2 + z^2 + w^2 + v}{u}$ 22

13) $x = 2y + 3z + 4w$ 23

14) $x = 2y + 3z + 4w$ 24

15) Write xy as a FOLGOL point 25

16) Write xy as a FOLGOL point 26

17) Write xy as a FOLGOL point 27

18) Write xy as a FOLGOL point 28

19) Write xy as a FOLGOL point 29

20) Write xy as a FOLGOL point 30

First Posttest for Experiment IV

NAME: _____

Please answer all of the following questions. If you do not know the answer, guess.

Translate in FORTRAN the following English or algebraic expressions:

- | | |
|---|-----|
| 1) A plus B minus C | 1) |
| 2) X divided by Y | 2) |
| 3) E multiplied by F | 3) |
| 4) $C_k = \frac{B_{jk}}{3.1}$ | 4) |
| 5) $A = B^2$ | 5) |
| 6) X multiplied by Y_1 | 6) |
| 7) $\frac{3.2 D}{A^3}$ | 7) |
| 8) $X = \left(\frac{Y}{Z}\right)^2$ | 8) |
| 9) $\frac{C_{jk}}{F}$ | 9) |
| 10) $A = \frac{X - Y - Z^2}{3.1 - B}$ | 10) |
| 11) $Y = \frac{C^2 - C^3 - 2.0 CB}{1.5C}$ | 11) |
| 12) $A = B(X_1 + X_2 + X_3)$ | 12) |
| 13) Write fifty as a floating point number. | 13) |
| 14) Write zero as a fixed point number. | 14) |
| 15) What is wrong with $Y=2.1*Z/(3*X)?$ | 15) |
| 16) What is wrong with $X(1.0)**2?$ | 16) |

Second Posttest for Experiment IV

(given 48 hours after the
first posttest)

NAME: _____

Did you study any of these topics since you answered the questions on Wednesday _____

Please answer all questions. If you do not know the answer, guess.

Translate the following English or algebraic expressions into FORTRAN:

- | | |
|--|-----|
| 1) $X = C(Y_2 - Y_3 + Y_4)$ | 1) |
| 2) $\frac{S_{1j}}{B}$ | 2) |
| 3) A multiplied by B | 3) |
| 4) $X = Y^3$ | 4) |
| 5) $B = \frac{Y + X^2 - Z}{1.5 + C}$ | 5) |
| 6) D plus E minus F | 6) |
| 7) X_1 multiplied by Y | 7) |
| 8) $X = \frac{A^5 + A^4 + 2.5 A D}{3.2 D}$ | 8) |
| 9) Write zero as a floating point number. | 9) |
| 10) What is wrong with $Y=2*X/(3.5*Z)?$ | 10) |
| 11) A divided by B | 11) |
| 12) $A_j = \frac{X_{1j}}{2.7}$ | 12) |
| 13) $\frac{5.1 X}{B^2}$ | 13) |
| 14) Write forty-five as a floating point number. | 14) |
| 15) What is wrong with $Y(3.0)**2?$ | 15) |
| 16) $Y = \left(\frac{X}{Z}\right)^3$ | 16) |